Job 1330
Project 50-7-229

SEMICHEMICAL PULPS FROM SELECTED ENGLISH HARDWOODS

(BROADLEAVED) FOR PRODUCTION OF CORRUGATING BOARD

(In cooperation with Bridgend Paper Mills Limited, London, England)

By

E. L. KELLER, Chemist
and
F. A. SIMMONDS, Chemist

NOT FOR PUBLICATION

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison 5, Wisconsin
In Cooperation with the University of Wisconsin

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Summary and Conclusions

In recognition of the general need to increase the use of locally available hardwoods for papermaking pulps, a study of the neutral sulfite semichemical pulping of several English hardwoods for the production of corrugating board was made at the U. S. Forest Products Laboratory in cooperation with the Bridgend Paper Mills Limited of London, England.

Two neutral sulfite pulps were produced. One of these pulps was made from a mixture of 50 percent of pedunculate oak, 15 percent each of ash and birch, and 10 percent each of beech and sycamore, all wood being peeled.

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Yield of pulp was 82.7 percent on moisture-free basis for both wood and pulp. The second pulp was made from unpeeled hazel, in yield of 79.9 percent. The characteristics of these woods were similar to those of North American hardwoods.

Corrugating boards were made from these pulps and combined to single-faced corrugated boards, using a commercial 16-point jute board for the liners.

Comparison of the corrugating and corrugated boards with commercial and experimental boards of like composition showed the boards made from the English hardwoods to be outstanding in quality.

Of especial interest is the high quality of board made from the hazel, despite the fact the bark was not removed from the wood.

Introduction

The need for increased use of locally available hardwoods as raw material for papermaking pulps is generally recognized.[2] The neutral sulfite semichemical process, developed at the Forest Products Laboratory, is especially suitable for producing pulps high in yield and in quality from hardwoods. The reduction of hardwoods to pulp by this process for the production of corrugating boards is well established in North America. An extension of this usage wherever desirable should be broadly advantageous.

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[2] Raw Materials for More Paper. FAO Forestry and Forest Products Study No. 6. Food and Agriculture Organization of the United Nations. Rome, April, 1953.

As a contribution toward this objective, a study of the neutral sulfite semichemical pulping of several English hardwoods for the production of corrugating boards was made at the U. S. Forest Products Laboratory in cooperation with the Bridgend Paper Mills Limited.

With respect to wood supply, the problem was approached realistically. One pulp was made from unpeeled hazel; the other, from a mixture of 50 percent pedunculate oak, 15 percent each of ash and birch, and 10 percent each of beech and sycamore. All of these woods were peeled before being pulped.

Each of these pulps was made into corrugating board on the Laboratory 12-inch-trim Fourdrinier paper machine. The corrugating boards were then combined to single-faced corrugated boards, using a commercial 16-point jute test liner. Both corrugating and corrugated boards were tested for comparison with other experimental and commercial boards.

Experimental Part

The Woods

Certain chemical and physical characteristics of several English hardwoods are given in table 1. The species used in the production of pulps for corrugating pulps have been enumerated in the foregoing. Visual inspection of these species, as well as the others listed in table 1, showed them to be in a sound condition. The test values reported were within the range of similar values for North American hardwoods. All data reported in table 1 were supplied by Bridgend Paper Mills Limited.

Each tree, after felling, had been divided into 3 portions. The top and butt logs were retained for testing in England, while the middle portions were shipped to the Forest Products Laboratory for use in the investigations reported here. The wood averaged 4 to 6 inches in diameter under the bark, except for the hazel. Two classes of hazel were received, one lot ranging from 1/4-inch tops to about 1 inch in butt diameter, while the second lot varied from 1 inch to slightly over 2 inches in diameter. All of the hazel and a portion of the oak were received unpeeled. The oak was hand-peeled before cooking, while the hazel was cooked with the bark on.

Neutral Sulfite
Semichemical Pulping

A typical 5/8-inch size of chip was used. Chips were screened to remove undesirably large and small pieces.

Since these chips were prepared from seasoned wood and were therefore relatively low in moisture when charged to the digester, they were steamed in the digester for 30 minutes at atmospheric pressure in all instances before the cooking liquor was added to the digester. Previous experience at the Forest Products Laboratory indicates this procedure minimizes the difference between green and seasoned wood in response to pulping. This steaming technique results in a moisture content of chips of about 50 percent.

After the preliminary steaming, the cooking liquor, comprising a mixture of technical sodium sulfite and sodium bicarbonate, was added. Respective concentrations, shown in table 2, were determined by titration.

For the mixture of hardwoods the volume of cooking liquor was 40 gallons per 100 pounds of wood (moisture-free basis) and for the hazel, 45 gallons. For cooking, a straight-line increase of temperature was used to attain a maximum of 170° C. during a period of 2.5 hours. This maximum was then maintained until the concentration of sodium sulfite in the cooking liquor had decreased to 10 grams per liter (table 2). Other cooking conditions and pulp yield values are given in this table.

In table 2, the digestion number suffix "y" indicates pulping was done in a digester of 0.8 cubic foot volume to establish suitable conditions for producing pulp at about 80 percent yield. The suffix "N" indicates pulping was done in a 13-cubic foot digester to produce pulps in sufficient quantities for papermaking trials. The cooked, but physically intact, chips from these large-scale digestions were fiberized to pulp by a single pass through a 36-inch No. 400 Bauer disk mill (commercial unit). Conditions of refining are given in table 2.

Board Making

The pulps from the hazel and the 5-species mixture were run on the paper machine without use of a sizing agent or mechanical processing. Freeness values for the stocks at the headbox of the paper machine were in the range of mill practice in the United States. Specifically, these were as follows:

Species	Freeness	
	Canadian Standard	Schopper-Riegler
	Ml.	Ml.
Hazel	465	710
Mixture of five	425	660

These corrugating boards were combined to single-faced corrugated boards with use of A-flute rolls and sodium silicate adhesive. The test liner was a commercial 16-point jute board.

Discussion of Results

Woods and Pulps

The high specific gravity of the hardwoods cooked in mixture, averaging better than 0.5 (table 1), indicated that a relatively high yield of pulp from a volume unit of wood or chips would be obtained. Generally speaking, the high pentosan and low lignin contents of the woods are typical of temperate hardwoods. The birch was characteristically high in pentosan content. Although the woods were relatively young, they had reached a satisfactory size for pulpwood. While the solubility of 5 percent of the oak in hot water was higher than that of the other English species examined, it is lower than certain North American oaks. A high solubility in hot water frequently corresponds to a low requirement of sodium sulfite for a given yield of pulp. However, the requirement of sodium sulfite for pulping

the mixture was about average. The consumption of the sodium bicarbonate buffer was considerable to effect a pH of above 7 in the spent cooking liquor (table 2).

As is also shown in table 2, yields of pulps were in the range of 80 to 83 percent. For comparison, a Wisconsin mill produces from aspen a corrugating grade of pulp in yield of about 80 percent. In general, strength of semichemical pulps is proportional to yield for a given species or mixture of species. The two pulps made in this study gave corrugating boards high in strength (table 3). Possibly pulp strength would still be adequate at the 84 to 87 percent range of yield.

Experimental Boards

Comparison of the test values for the corrugating boards made from these pulps (Machine Run Nos. 4380 and 4381, table 3) with similar values for other experimental and commercial boards included in table 3 shows their quality was high. For example, the boards made in this study averaged about 11 percent higher in the ring-crush test than did the other boards selected as typical for comparison. This test was made in accordance with TAPPI Standard T-472m. The apparatus and procedure used at the Forest Products Laboratory is described in Reprint No. 1 in the appendix. As is brought out in this reprint, and also in Reprint No. 2 (appendix), results of this test have been shown related to resistance of shipping containers to top to bottom crushing loads. Other crush tests also used in industry on uncombined boards include the single-flute and Concora[3] methods.

[3]Concora Medium Tester. "A New Test for Corrugating Medium," F. E. Long and G. G. Maltenfort (Container Corporation of America) Fibre Containers and Paperboard Mills 34, No. 12, 86, 91, 92, (December 1952).

The single-faced corrugated boards were tested by means of the flat-crush test which is used widely in the domestic board industry. Test values in the last column of table 3 show the corrugated boards made in this study averaged about 25 percent higher than did the boards used for comparison.

Of especial interest is the high quality of board made from the hazel, despite the fact the bark was not removed from the wood.

Samples of the corrugating boards and single-faced corrugated boards are included in the appendix.

The high quality of the boards produced from the English hardwood semichemical pulps thus offers at least two possibilities of interest in mill practice. A higher yield of pulp than those presently made might be produced or pulps of the same yield might permit blending in appreciable quantities of pulped waste papers.

Experimental Equipment

Experimental equipment used in this investigation is illustrated and described in Reprint No. 3, Appendix.

Table 1.--Test values[1] for several English woods

Common name	Botannical name	Rate of growth	Heartwood by volume	Age	Specific gravity[2] (based on ovendry weight and green volume)	Ash[3]	Alcohol-benzene solubility[4]	Hot-water solubility[5]	Cellulose by chlorination[6]	Lignin[7]	Pentosan[8]
		Rings per in.	Percent	Yr.		Percent	Percent	Percent	Percent	Percent	Percent
Ash	*Fraxinus excelsior*	7.0	(9)	15-17	0.53	0.30	1.95	2.6	53.4	18.9	22.8
Beech	*Fagus sylvaticus*	11.1	(9)	4-1	.56	.26	1.07	1.15	53.7	22.4	19.8
Birch	*Betula pubescens*	6.9	(9)	12-25	.50	.29	1.73	1.7	53.9	17.9	27.2
Hazel	*Corylus avellana*										
Hornbeam	*Carpinus betulus*	16	(9)	44	.58	.38	1.70	2.45	52.6	18.7	26.8
Norway spruce	*Picea abies*	11.9	(9)	27-28	.45	.21	1.21	1.3	54.4	26.2	10.7
Pedunculate oak	*Quercus robur*	12.7	60.2	39-49	.55	.22	1.91	5.0	54.4	17.0	22.2
Sweet chestnut	*Castanea sativa*	6.5	76.8	14-17	.48	.28	1.78	7.84	54.7	18.1	23.4
Sycamore	*Acer pseudoplanatus*	6.5	(9)	15-18	.47	.37	2.17	3.16	52.1	19.7	22.0

[1] Data were supplied by the Bridgend Paper Mills Limited, except for hazel.

[2] Averages for top and butt portions. Average diameter under bark was 4 to 6 inches, except hazel, which varied from about 1/4 inch to 2 inches.

[3] After burning at 600° C.

[4] TAPPI Method T6-m50.

[5] TAPPI Method T1-m51.

[6] Cross and Bevan method, confirmed by Jenkins method.

[7] Willstatter method.

[8] Calculated from furfural.

[9] Heartwood not distinguishable.

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Table 2.--Neutral sulfite semichemical pulping of several English hardwoods for corrugating board and certain results

Species	Hazel	Hazel	Mixed[1]	Mixed[1]
Digestion number[2]	1174-y	5571-N	1171-y	5572-N
Bauer mill run number[3]		1020		1019
Cooking conditions[4]				
Liquor charged				
Volume, gal. per 100 lb. wood	45	45	40	40
Concentration: sodium sulfite, gm. per l.	33.3	28.7	32.6	29.4
sodium bicarbonate, gm. per l.	22.1	22.9	20.7	23.7
Amount of chemicals per 100 lb. of wood				
sodium sulfite, lb.	12.5	10.8	10.9	9.8
sodium bicarbonate, lb.	8.3	8.6	6.9	7.9
Maximum temperature, °C.	170	170	170	170
Time at maximum temperature, hr.:min.	0:40	0:30	0:40	0:15
Spent liquor, pH	6.8	6.9	6.8	6.8
Bauer milling conditions[5]				
Plate clearance, 0.001 in.		5		7
Feed speed setting		3		2.5
Consistence, percent		10.5		11.4
Unit energy consumed, hp.-days per A.D. ton		18.9		19.1
Freeness of pulp directly from mill, Canadian Standard, ml.		510		500
Pulp yield, unscreened, percent	77.2	79.9	78.2	82.7
Pulp lignin content, percent		16.6	15.3	15.0

[1] Oak, 50 percent; ash and birch, each 15 percent; beech and sycamore, each 10 percent.

[2] Small-scale digestions are designated by the letter "y" and large scale by "N."

[3] Bauer mill run numbers are assigned only when commercial-size mill is used.

[4] Constant conditions for pulping: Chips steamed 0.5 hour before adding liquor, 2-1/2 hours to maximum temperature. Concentration of sodium sulfite in spent liquor was about 10 grams per liter. Basis for calculations: 100 pounds moisture-free wood.

[5] 36-inch Bauer No. 400 double-disk refiner. No. C914 plates operate counterclockwise. Feed: slow sheave, feed slide closed. Basis for calculations: 1 ton air-dry pulp, 90 percent dry.

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Table 3.--Data on several corrugating boards and the corresponding corrugated boards

Furnish	Shipment No.[1]	Machine run No.[1]	Weight: Of 1,000 square feet	Weight: Of a ream[2]	Thickness	Density	Burst factor	Tearing resistance[3]	Tensile strength[3]	Ring crush[3]	Flat crush[4]
			Lb.	Lb.	Mils	Gm. per cc.	Pts. per lb. per rm.[2]	Gm. per lb. per rm.[2]	P.i.w.	Lb.	P.s.i.
HARDWOOD NEUTRAL SULFITE SEMICHEMICAL PULPS											
Pulp plus screenings	3152		24.0	83.4	8.2	0.56	0.58	1.22	38.5	53.0	28.6
Aspen[5]	4044		26.3	91.3	7.9	.64	.56	.76	37.7	52.0	
Do...........		4261	26.3	91.7	7.5	.68	.62	.89	40.5	50.5	27.9
Aspen, 95 percent; softwood kraft, 5 percent	2559		26.8	93.4	7.6	.68	.61	.80	44.4	58.0	
Chestnut	9000		26.6	92.5	8.9	.57	.27	.58	20.6		
Mixed domestic species, 80 percent; waste paperboard, 20 percent		3556	26.0	90.3	8.5	.59	.52	1.02	34.7	52.3	29.2
Mixed English species[6]		4380	27.3	94.7	7.7	.68	.71	1.23	45.2	58.4	32.3
Hazel[7]		4381	26.4	91.8	7.3	.70	.79	.82	49.0	60.5	35.9
OTHER COMMERCIAL PULPS											
Straw	41-A		32.5	113	9.9		.24				21.8
Southern kraft	41-B		25.0	87	9.0		.74				29.0

[1] Shipment numbers indicate commercial boards; machine run numbers indicate experimental boards.

[2] Ream of 500, 25-inch by 40-inch sheets.

[3] Strength values are average for the two machine directions.

[4] Values obtained on A-flute, single-faced corrugated boards.

[5] The same commercial semichemical pulp was used in these two furnishes.

[6] Oak, 50 percent; birch and ash, 15 percent each; beech and sycamore, 10 percent each. Digestion 5572-N, made from peeled wood.

[7] Digestion 5571-N, made from unpeeled wood.

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APPENDIX

Development of Design Data for Corrugated Fiberboard Shipping Containers

Reprint No. 1

Development of Design Data for Corrugated Fiberboard Shipping Containers

Development of Design Data for Corrugated Fiberboard Shipping Containers

K. Q. KELLICUTT and E. F. LANDT

The evolution of a formula for predicting the top-to-bottom compressive strength of corrugated A, B, and C-flute boxes from ring-crush or strip-column tests of the component paperboard sheets is discussed. Application of the formula for use in design of corrugated fiberboard boxes to meet specific use requirements is shown. The relationship between the static compressive strength of boxes, dead load of storage, and duration-of-load are included as well as a means of interpreting the known compressive strength of a box having a specific moisture content in terms of another moisture content of the fiberboard.

The Quartermaster Food and Container Institute for the armed forces has collaborated for several years with the Forest Products Laboratory on a basic study to develop design criteria for use with corrugated fiberboard shipping containers. This investigation included consideration of earlier studies that involved the evaluation of paperboard and corrugated fiberboard as engineering materials and showed the strength properties of the component sheets to be correlated with those of the built-up board (*1*, *3*, *4*). A similar correlation between certain strength properties of a box and those of its components, which would appear to be the next logical step, is the subject of this paper. It describes results, to date, of simplifying and interpreting tests of the components and shows how these results are used in a method that was developed to predict the compressive strength of corrugated fiberboard boxes.

TESTS AND PROCEDURES

Several forms of material and test methods were used in this investigation: (1) component paperboard sheets were subjected to ring-crush, modified ring-crush, and strip-column tests; (2) built-up corrugated boards were given bending, shear, and flexural-shear tests*; (3) fiberboard structures, called tubes, consisting of four panels representing a box without top or bottom were given compression tests; and (4) conventional slotted boxes were given compression tests and were tested in a revolving drum with can-type loads.

Material, Method of Construction, and Size of Tubes and Boxes

Material. All of the tubes and boxes tested were made of double-faced corrugated fiberboard. Some of the A and B-flute board was made on the Laboratory's corrugator and was of balanced construction having the same basis weight of jute or kraft for both liners in combination with either straw, kraft, pinewood, chemfiber, chestnut, or aspen corrugating mediums.

Other boards and boxes were of A, B, and C-flute construction fabricated in commercial corrugated-box factories. Not all of these boards were of balanced construction, although all were made of paperboard component materials currently being used commercially. Some of the boxes were made at the Laboratory from V3c and W6c boards produced commercially. Other V3c boxes tested were made by a commercial fabricator. Samples of the component materials of all the boards were tested.

Method of Constructing Tubes and Boxes. The blank from which each tube was made was cut to the proper size with a sharp power saw in order to eliminate the crushing and tearing of the liners and corrugations along the edges that result when a shearing blade is used for cutting. The joint was made with cloth-backed tape, 3 in. wide, applied to the inside and outside surfaces of the joint and overlapped on each panel about $1^1/_2$ in.

The boxes made and tested were the regular slotted type and had manufacturer's joints fabricated by stitching, tape, or glue. The top and bottom flaps were sealed with adhesive.

Sizes of Tubes and Boxes Tested. Tubes were made from Laboratory boards in a variety of sizes, from 2 to 35 in. square. The heights of the tubes varied from 2 to 48 in.

The tubes and boxes made from commercial materials included not only square but oblong cross sections, in which the length dimensions were either two or three times the width dimension. The perimeters of these tubes and boxes ranged from 16 to 120 in., and their heights were between $6^1/_2$ and $36^7/_8$ in.

Tests of Paperboard Components

Modified Ring-Crush Test. A modified ring-crush test for paperboards, which was developed at the Laboratory, was employed to determine the stress at proportional limit, stress at maximum load, and modulus of elasticity of liners and corrugating mediums. The test specimen consisted of a number of layers of a paperboard strip rolled into the form of a hollow cylinder. The end of the outside lap was secured to the cylinder by a fine line of adhesive. To provide flat ends for insertion in the testing machine, the ends were cast in a compound of ester gum and sealing wax. Two optical strain gages were attached to each specimen.

K. Q. Kellicutt, Engineer, and E. F. Landt, Technologist, Forest Products Laboratory, maintained at Madison, Wis., in cooperation with the University of Wisconsin, Forest Service, U. S. Department of Agriculture.

* The procedures for tests of built-up corrugated board and their significance have been previously discussed (*6*) and will not be repeated in this paper.

By measuring compression over a definite gage length on each of two opposite sides of the specimen, reliable data were obtained for use with simultaneous readings of the applied load. Some specimens were prepared so that the load could be applied parallel to the "with-machine" direction of the paper, while others were prepared so that the load could be applied parallel to

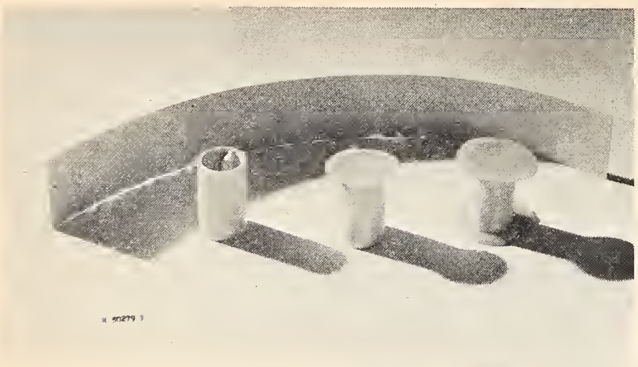


Fig. 1. A specimen for the modified ring-crush test in various stages of preparation

The specimen is prepared by coiling a paper strip (background) on a removable core and casting the ends of the coil. One end has been cast on the specimen in the center. Both ends have been cast on the specimen on the right, which is ready for insertion in the testing machine.

the "across-machine" direction. The components of the modified ring-crush specimen and the specimen in a testing machine are shown in Figs. 1 and 2.

Ring-Crush Test. Ring-crush tests were made by testing $^1/_2$ by 6-in. strips bent into a ring in a specimen holder. The rings were supported on their inner surfaces by the removable centers, or islands, of the holder. The removable islands varied in diameter and were chosen according to the thickness of the specimen. The strips were crushed in a machine that yielded a single value, that of maximum load. The specimen holder for the ring-crush test, and a specimen cutter are shown in Fig. 3.

Strip-Column Test. A strip-column test was made on a specimen 4 in. long that was held straight between two sets of clamp supports, so as to provide a column $^1/_{16}$ in. high. As with the ring-crush tests, only a single value of maximum load was obtained as a result of crushing the column in a testing machine. The clamp employed and the type of test specimen used are shown in Fig. 4.

Compression Tests of Tubes and Boxes

To determine the relationships of size, shape of cross section, and height involved in the bending and crushing of the side walls, compression tests were made of tubes and boxes. The tests were made in a universal testing machine that had a mechanism for making an autographic load-compression curve of each test. Before test the tubes and boxes were conditioned in a controlled atmosphere. The direction of the flutes in the side walls of the tubes and boxes was either vertical (parallel to the direction of the applied load) or horizontal (perpendicular to the applied load).

Drum Tests of Loaded Boxes. A number of drum tests were made of various kinds of boxes, including those made of A, B, and C-flute boards with either jute or kraft liners. The boxes had can-type loads, and the weight of the contents was approximately 1 lb. for each inch of length plus height plus width. Failure was considered complete when the contents spilled from the box during the drum test.

DISCUSSION OF RESULTS

It was apparent in the initial studies at the Laboratory that the strength properties of corrugated fiberboard and the component paperboard materials could be obtained from tests designed to yield engineering information. In the early tests the modulus of elasticity of paperboards, as determined by a tension test, was found to correlate with engineering data from column, bending, and shear tests of the built-up corrugated board. It was desired also to determine if a similar correlation could be obtained for compressive stresses. The modified ring-crush test, one of the more precise tests for compressive stresses, was found to be useful in correlating the maximum crushing loads of

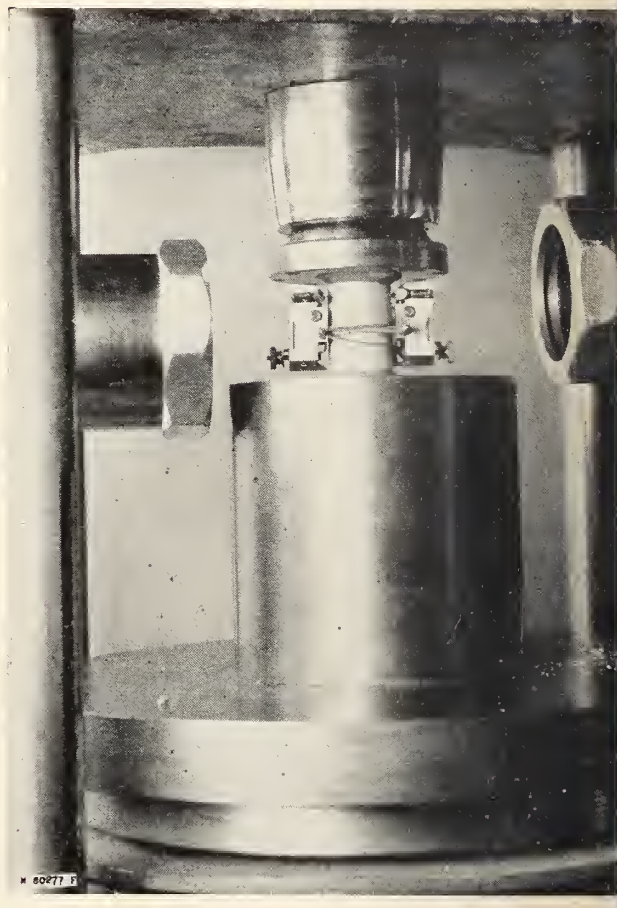


Fig. 2. A specimen for the modified ring-crush test, with two optical strain gages attached, is oriented in the testing machine. The ends of two auto-collimators, for reading the gages, may also be seen

fiberboard tubes with the maximum crushing strength of paperboard. Its principal use in this study, however, was to evaluate simpler tests, such as the ring-crush and strip-column tests. Both the ring-crush and strip-column tests are considered suitable for use by

ıdustry, and it appeared logical to explore the feasiility of using them in accomplishing the main objecves of this investigation.

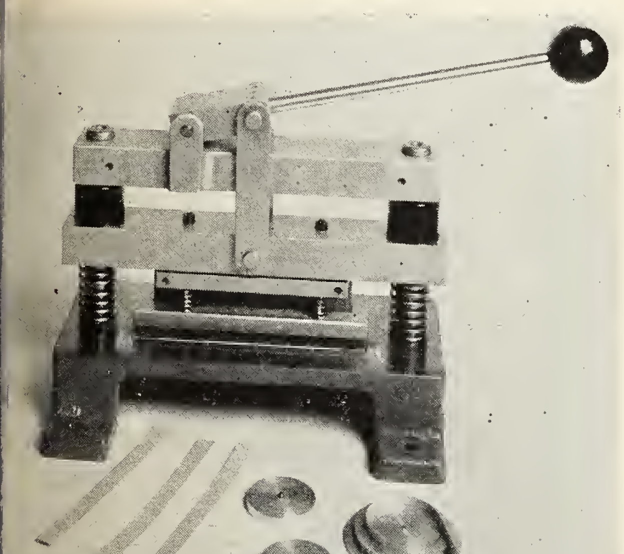
volution of a Design Formula

One of the main objectives of this investigation was to evelop a method of expressing the crushing strength of corrugated fiberboard box using information obtained om a simple test of the component paperboard sheets. n the development of this method, the tube was used s the intermediate link between tests of the comonents and of the box. Therefore, the mathematical elationships involved in the bending and crushing of nin plates representing each of the four walls of a berboard box were initially established for the tube.

As paperboard is a nonisotropic material, it was ecognized that a formula applicable to fiberboard with ne load applied parallel to the machine direction might ot be applicable to fiberboard with the load applied erpendicular to the machine direction of the fourrinier or cylinder paperboards. With these recognized naracteristics as a guide a basic formula was evolved or the crushing strength of a tube that paralleled data eveloped at the Forest Products Laboratory for pplying the thin-plate theory of mechanics to the esign of panels of plywood (*7–10*).

elationship of Static Tube and Box Loads

The static compressive strength of tubes represents



ig. 3. Strips of paperboard $^1/_2$ by 6 in., left front, are ut for the ring-crush test with the specimen cutter in he background. The specimen holder for the ring-crush est is shown at the right front with a paperboard strip artially inserted in it. In the center front are two reiovable islands for the specimen holder that are used with other thicknesses of paperboard

ne optimum that may be obtained with any given orrugated board, and it follows that this optimum ompressive strength will not be attained in correonding corrugated fiber boxes because of various ıctors that enter into their manufacture and use. Hence, in order to use the formula developed for the crushing strength of a tube for design purposes, it was necessary to establish the relationship between the loads attained by tube and by the box.

To determine the relationship of the crushing strength of fiberboard tubes to the top-to-bottom crushing strength of the finished fiberboard box, comparisons of

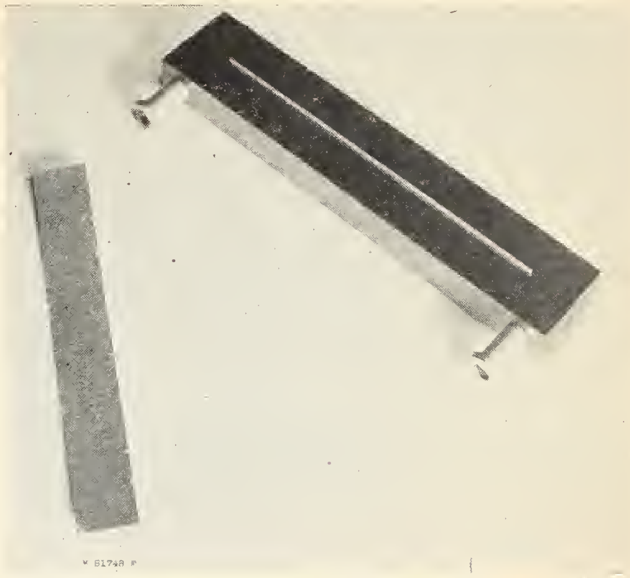


Fig. 4. The strip of paperboard, $^9/_{16}$ by 4 in., held in the metal clamps at the right, is ready for the strip-column test. A $^1/_{16}$-in.-high column of paperboard is provided above the top surface of the clamps. A test specimen is shown on the left.

tube and box loads for corresponding sizes were made. These comparisons, which included boxes and tubes with square and oblong cross sections in various heights, showed that the relationship was fairly constant up to certain limits. For instance, for tube loads up to about 1500 lb., the box loads were approximately 0.7 of the corresponding tube loads. For tube loads greater than 1500 lb., the ratio of box loads to tube loads was no longer constant but decreased with an increase in tube load. It was observed that the tube loads continued to increase beyond the 1500-lb. value, while the corresponding box loads did not change appreciably.

In general, the maximum load that tubes of a given cross section withstood decreased with an increase in height from 2 in. up to 12 or 16 in. depending upon the kind of material from which the tube was made. A further increase in height had little influence on resistance to crushing. This can be explained by the fact that the 12, 14, or 16-in. heights represent the wavelength into which any particular combination of material would shape itself under stress and that the greater heights were merely multiples of this wave length (*2*). This fact is illustrated by the tests of the two tubes shown in Figs. 5 and 6.

Increases in the compression strength of boxes did not occur, however, with decreases in height. This can be accounted for, at least in part, by the end condition of the side panels of the box. Rolling and bending takes place along the horizontal score, which

is one of the weaker points in a box, and usually causes premature buckling. As a result the loads attained by shorter panels in a box are not greater than those attained by higher panels as they are in a tube where normal buckling occurs. Although some differences in loads were attained for boxes of various heights, for practical purposes, the box loads were considered the same for a specific cross section, regardless of height.

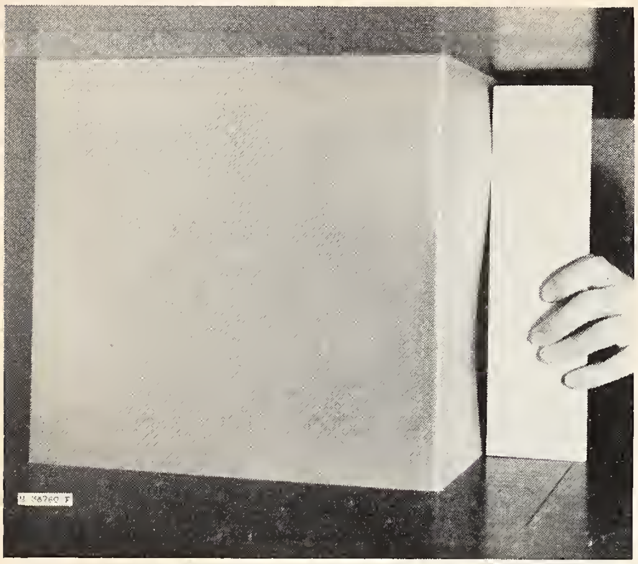


Fig. 5. Compression test of a 12 by 12 by 12-in. tube showing a wave in the direction of applied load. The tube shown was fabricated from B-flute board having 0.030-in. jute liners and 0.009-in. straw corrugations

Determination of Box Factors

The box factor, or ratio of box load to tube load, for various cross sections and for heights of 12 in. and greater was reasonably constant. For heights of less than 12 in., however, there was considerable divergence between the box and tube loads. This was because tube loads increased with decreasing heights while the box loads remained about constant throughout the range. Therefore, to eliminate this divergence by deriving a box factor that would apply regardless of the shape of the box, it was necessary to relate the box to a tube in which the ratio of the width of a side panel to the height of the panel was 1.5 or less.

Although it was found that a single box factor could be used for a specific flute, the same factor could not be used for all three flutes. Hence, box factors were determined for A, B, and C-flute boxes, so that box loads could be predicted from the basic tube formula. Further, it was found that the box factor provided a means for adjusting box loads for the specific kinds of body joints. Some tentative box factors that were determined are included in Table I.

Alignment Charts for Application of Formula to Boxes

To simplify use of the formula for boxes, alignment charts for calculating the strength of A, B, or C-flute boxes were constructed (*6*). A typical chart, for A-flute boxes, is shown in Fig. 7. To use the alignment charts, determine the combined ring-crush strength of the single-face liner (S.F.L.), the double-back liner (D.B.L.), and the corrugating medium (C.M.). Fo[r] A-flute boxes, this strength is determined by th[e] formula

$$\text{S.F.L.} + \text{D.B.L.} + (1.523 \times \text{C.M.})$$

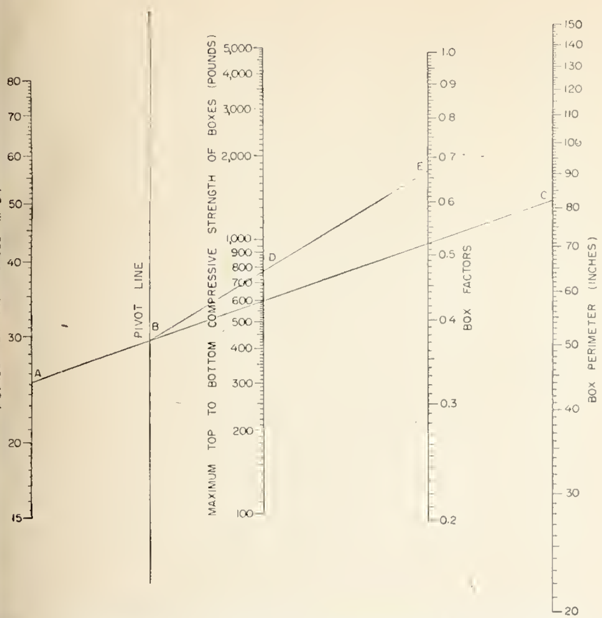
Table I. Tentative Box Factors for A, B, and C-Flute Box[es]

Source of boxes	*Type of manufacturer's joint*	*Box factors for boxes with flutes vertical in side walls*[a] — *Flute* — *A*	*B*	*C*
Laboratory made from commercial material	Taped	0.717	0.752	0.717
	Stapled	. . .	0.622	. . .
Commercially made	Taped	0.667	0.597	0.667
	Stapled	. . .	0.564	. . .

[a] Box factors for boxes with flutes horizontal in side walls have not be[en] determined.

Fig. 6. Compression test of a 12 by 12 by 48-in. tub[e] showing longitudinal waves just before the maximu[m] load was reached. The tube was fabricated from th[e] same board used for the tube in Fig. 5. The load for th[e] two tubes was about equal

or B and C-flute boxes, the same formula is used, ꝁcept that the take-up factor for the corrugating ıedium will be 1.361 and 1.477 for B and C-flute boxes, ꞩspectively. With the combined ring-crush strength ıd the appropriate box factor the top-to-bottom ꞩushing strength can be determined from the align- ıent charts as illustrated for A-flute boxes in Fig. 7.



ig. 7. ***Alignment chart for determining the top-to-ottom compressive strength of A-flute corrugated fiber-oard boxes when the flutes are vertical in the side walls. he resulting determinations will be for a box conditioned ı the same atmosphere in which the ring-crush strength values were obtained***

sing a straightedge, connect the appropriate combined ng-crush strength, point A, with the box perimeter, oint C. With point B as a pivot, orient the straight-dge with the box factor, point E, and read the load on ıe compressive strength scale at point D.

tacking Strength of Boxes

The compressive strength provides an index for etermining other significant properties of the box of hich one of the most important is stacking strength. t is known that corrugated fiberboard boxes cannot be xpected to support indefinitely a stacking load equiv-lent to the load attained by a compression test of the ox in a testing machine. Although some large users of berboard containers have established their own stack-ıg limits for boxes in storage (*4*), and some basic tudies on stacking loads are in progress, more work needed to determine the portion of the compression est value that the box can be expected to support for pecific periods of time in various storage atmospheres.

To determine the information deemed necessary to stablish load limits for specific periods of storage, long-me loading tests were made of several kinds of A nd B-flute boxes in several different atmospheres (*5*). he results thus far obtained indicate clearly defined rends and relationships between the compression test alue of a box, as determined in a testing machine, he magnitude of the dead load of storage, and the uration of loading. These relationships were the same for various atmospheres. Hence, it was determined that the influence of moisture content of the fiberboard could be tied in directly with design by determining its influence on compressive strength.

Relation of Moisture Content of Fiberboard to Compressive Strength

The influence of moisture content on the compressive strength of various lots of boxes, made of different materials, was determined. A formula was derived (*5*) with which the compressive strength of a box at a specific moisture content may be found by relating the box to one for which the compressive strength and moisture content are known.

For easier use of the relationship, an alignment chart was constructed from which the compressive strength of boxes at one moisture content can be readily interpreted in terms of another moisture content (*5*).

Resistance to Rough Handling in the Revolving Drum

Although it was anticipated that general trends could be established, a close correlation between compressive strength and the results of rough-handling tests in the hexagonal drum was not expected. Past experience had shown that the drum test is less precise than the compression test, and that test values vary more for boxes tested in the drum than for those tested in the compression machine. Generally, the boxes that attained the greatest compressive loads also attained the greatest number of falls in the drum.

HOW CAN BASIC DESIGN DATA BE USED

It is believed that the information obtained in this study of fiberboard boxes and their basic component paperboard sheets can be used:

1. To prepare tables and charts for design purposes and general specifications applicable to various box sizes, load limits, and, perhaps, commodity classifications.
2. To develop design criteria that can be used by the box manufacturer in quality-control operations as well as for design purposes to meet specific use requirements or standards.

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Basic Design Data for Solid Fiberboard Shipping Containers

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Paper discusses the use of a formula for predicting the top-to-bottom compressive strength of solid fiberboard boxes as well as a means of interpreting the strength values for various moisture conditions of the fiberboard and a means of determining stacking loads of boxes in storage. It also discusses the box strength calculator, which simplifies the use of design data for both solid and corrugated boxes.

Introduction

Reprint No. 2

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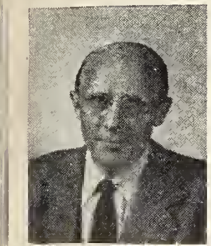
Basic Design Data for Solid Fiberboard Shipping Containers[1]



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Paper discusses the use of a formula for predicting the top-to-bottom compressive strength of solid fiberboard boxes as well as a means of interpreting the strength values for various moisture contents of the fiberboard and a means of determining stacking loads for boxes in storage. It also discusses the box strength calculator, which simplifies the use of design data for both solid and corrugated boxes.

Introduction

NUTS, BOLTS, STOVES, refrigerators, washing machines, furniture, food, clothing, and literally thousands of articles today are packaged, shipped, stored, displayed, and sold in fiberboard containers. New uses are continually being made of fiberboard and have accounted for the phenomenal growth of the industry in the past 50 years. In recent years the growth has been especially significant to the South where paperboard and fiberboard box manufacturers have expanded their facilities.

Because of this rapid growth, research has lagged developments in this field. Although much has been done in the way of basic studies of fiberboard for shipping containers, and much information has been accumulated (*5, 6*)[3] as a result of experience on the performance of fiber containers, more work needs to be done. Better and cheaper methods need to be developed for making fiberboard water resistant. This would provide many new uses for fiberboard. Also, more meaningful specifications for fiberboard boxes need to be developed.

Recognizing the need for design criteria for use of fiberboard in shipping containers, the Quartermaster Food and Container Institute for the Armed Forces has collaborated for several years with the Forest Products Laboratory on basic research involving the strength properties of the component paperboard sheets, the built-up board, and the finished fiberboard box.

The work has been undertaken in two phases. The first phase, development of design criteria for corrugated shipping containers, is partially completed (*7, 8, 9, 10*). The second phase, which primarily involves solid fiberboard, has been started. This paper will present some of the work that has been done in the second phase of the work.

Since similar materials are used in corrugated fiberboard and solid fiberboard, and since many of the relationships that were established for corrugated fiberboard boxes also apply to solid fiberboard boxes, the first logical step is to summarize the work that has been done on corrugated fiberboard.

Phase I—Background Information

Early studies at the Forest Products Laboratory showed that the strength properties of the component paperboard sheets could be correlated with those of the built-up board (*1, 2, 3, 4*). However, the early studies, which involved the evaluation of paperboard and corrugated fiberboard, made use of testing techniques that were considered too exacting and precise for general use (*1*). Simple testing techniques were needed before the use of design criteria could be made practical. Therefore, when the work was resumed after World War II (the study was inactive during the war), the primary objective was to develop simple testing techniques (*7, 9*). Several techniques were tried and evaluated. The most promising component tests were found to be the ring-crush test and strip-column test.

Formulas were evolved (*7*) in which the test values obtained with either the ring-crush or strip-column test of paperboard sheets could be used to predict the compressive strength of corrugated boxes. When the same testing techniques were tried with the components of solid fiberboard, the strip-column test was found to be the most applicable. The heavier strips of paperboard used in making solid fiberboard, especially the filler sheets, often checked or cracked when they were formed into the circular ring-crush specimen holder. This did not occur when the strips were held straight between two edge clamps in the strip-column test.

Development of a Design Formula for Corrugated Fiberboard Boxes: The work that had been done at For-

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[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] Italic figures refer to articles listed in the Literature Cited.

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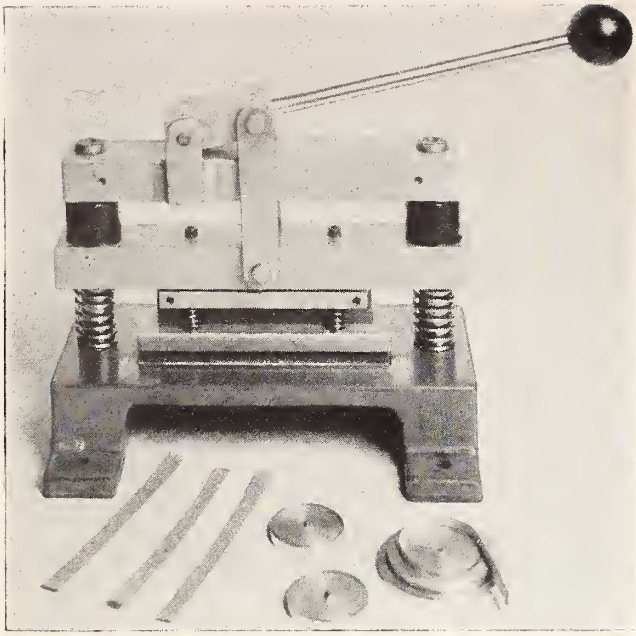

Figure 1.—Specimen cutter used to prepare test strips of paperboard 1/2 by 6 inches for either the ring-crush test or strip-column test. Sample strips and a ring-crush specimen holder are shown in the foreground.

Figure 2.—A paperboard strip, together with one properly inserted in the edge clamps used for strip-column test.

est Products Laboratory on applying the thin plate theory of mechanics to design of plywood (*11, 12, 13, 14*) provided a basis for a design formula for corrugated fiberboard and later for solid fiberboard. The theory could be applied because both of these materials are like plywood in that they are nonisotropic. From the plywood formulas, a basic design formula was evolved for corrugated board. This basic formula was modified and simplified several times and resulted in the following formula for predicting the top-to-bottom compressive strength of A-, B-, and C-flute boxes when the flutes are vertical in the side walls:

$$P = P_x \left(\frac{a_{x_2}^{2}}{\left(\frac{Z}{4} \right)^{2}} \right)^{1/3} ZJ$$

in which

P = total compressive strength of box in pounds

P_x = composite ring-crush load of built-up board (pounds per inch)
(P_{r1} single face + P_{r1} double back + $\propto xP_{rc}$)

P_{r1} = ring-crush load in pounds per inch of a 1/2- by 6-inch strip of liner either in the with- or across-machine direction, dependent upon P

P_{rc} = ring-crush load in pounds per inch of a 1/2- by 6-inch strip of corrugating medium in the across-machine direction

$\propto$ = ratio of length of corrugating medium when flat to its length when corrugated (A-flute = 1.523, B-flute = 1.361, C-flute = 1.477)

a_{x_2} = either 8.36, 5.00, or 6.10 for A-, B-, or C-flute, respectively

Z = perimeter of box in inches

J = box factor for the appropriate kind of fiberboard
A-flute = 0.59
B-flute = .68
C-flute = .68

To simplify the use of the formula, alinement charts were constructed for A-, B-, and C-flute boxes (*7*).

To further simplify the use of the data, a box strength calculator was developed (*10*). The calculator, which consists of five circular disks with various scales and indexes with a hair-line indicator, can be used to solve design problems by simple manipulations of the disks of the calculator. It incorporates design data for corrugated fiberboard as well as some of the information that has been accumulated for solid fiberboard.

Phase II—Solid Fiberboard

Several forms of material and test methods are being used to develop design criteria for solid fiberboard boxes. Component paperboard tests are made with the strip-column technique; structures, such as tubes (a box without top and bottom), and boxes are being tested in compression, and some dead-load tests are being made with boxes. The tests are being conducted in various atmospheres so that the effect of moisture content of the fiberboard on compressive strength can be determined.

Strip-column Test: The strip-column test was used to test components of the solid fiberboard. The test specimens were of the same size and cut with the same specimen cutter used for preparing the ring-crush test specimens (fig. 1). The cut specimens, 1/2 by 6 inches, were held straight between two clamp supports (fig. 2) so as to provide a column of paperboard 1/8-inch high above the clamps. The column was crushed in a testing machine where only a single value, that of maximum load, was obtained. Specimens were prepared so that both the with-machine and across-machine directions of the paperboard components could be tested. The tests were conducted in a room maintained at 75° F. and 64 percent relative humidity.

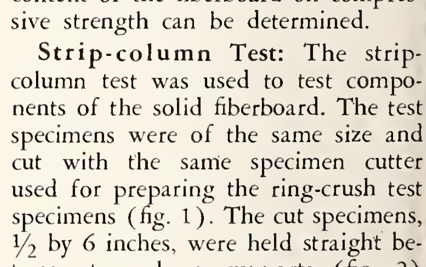

Figure 3.—Typical buckling curves for cubical A-flute corrugated tubes and cubical solid fiberboard tubes in sizes ranging from 6 to 24 inches.

Table 1—MAXIMUM STRIP-COLUMN CRUSH VALUES OF TYPICAL LINERS AND PAPERBOARD FILLER STOCK

Material and description	Basis weight Lb./1,000 sq. ft.	With-machine direction Lb./in.	Across-machine direction Lb./in.
Liners			
1. Fourdrinier kraft	42	15.9	9.8
2. Fourdrinier kraft	54	17.4	12.6
3. Jute	85	29.8	16.1
Filler			
1. Plain chip	100	18.3	11.0
2. Plain chip	118	23.6	14.1
3. Plain chip	137	28.6	17.4

The with-machine values were as much as 1.85 times as great as the across-machine values for the various liner boards tested. For the filler sheets, the values for the with-machine direction were as much as 1.67 times as great as the across-machine direction. Typical values resulting from the strip-column test for some liner boards, as well as for some of the filler sheets, are shown in table 1.

Relation of Strip-column Values to Built-up Board: It was found that the single strip-column values of the component sheets could be added to provide a composite value for the built-up board. Although these composite values were lower in most instances, they correlated well with the actual crushing loads attained for samples of the built-up board. The higher values attained for the built-up board can be accounted for by the additional stiffness resulting from the adhesive used on the components of the built-up board. Also, the inner sheets of the board are restrained by the outer sheets and attain higher crushing and buckling values than when tested without support. The tests of the built-up board consisted of strips ½ by 3 inches supported in the same edge clamps that were used for the strip column and arranged to provide a free column of ⅛ inch above the clamp. Test values for the built-up board, individual values for the component paperboard sheets, and composite values obtained by adding the component values are shown in table 2.

After this relationship between tests of the components and tests of the built-up board was established, it became apparent that the same general scheme could be used to calculate the compressive strength of a structure fabricated from the built-up board as had been developed for corrugated board, provided the relationships that had been established for corrugated board, involving size and shape of cross section and height of the tube, were the same.

Compression Tests of Solid Fiberboard Cubical Tubes: Top-to-bottom compression tests were made on cubical tubes fabricated in the Laboratory from sheet stock obtained from several commercial box plants. The tests included sizes of 4-, 6-, 8-, 12-, 16-, and 24-inch cubical tubes with the machine direction of the paperboard either parallel or perpendicular to the applied load. The results of these tests on solid fiberboard tubes revealed that the same relationships between load and size did exist that had been found for corrugated board in previous studies. The buckling curve for cubical corrugated tubes and a similar curve for cubical solid fiberboard tubes are shown in figure 3. Although the curves converge slightly for the small sizes, they are generally the same shape and slope. The slope of the curve for solid fiberboard tubes was found to be one-third, the same as had been previously calculated for corrugated tubes. Therefore, the same general formula, with slight modification, could be used for calculating the top-to-bottom compressive strength of the solid fiberboard tubes and boxes.

Modification of Formula to Apply to Solid Fiberboard: The formula was modified by including a factor representing the grain direction of the fiberboard with respect to the applied load and a box factor in the formula for P. By comparing actual tube and box loads, the box factor was found to be 0.70. By using values from the strip-column test rather than the ring-crush test for the determination of P_x quantities, good correlation was found between actual top-to-bottom compressive test loads and calculated loads for solid fiberboard boxes (table 3).

Development of Duration-of-load Information for Solid Fiberboard Boxes: It had been known that fiberboard boxes cannot be expected to support a stacking load equivalent to the load attained by a compression test of a box in a testing machine. In previous tests of corrugated boxes it was found that dead loads that approached the static compressive strength of the box caused failures usually within minutes (8), while dead loads of about 60 percent of the compressive strength caused failure in about a month. From tests of many corrugated boxes, conditioned in various atmospheres, the relationship between the machine test load, dead load of storage, and the duration of load was established (fig. 4).

Using the relationship thus established, duration-of-load tests were made with solid fiberboard boxes, and the failures were found to follow the same trends (table 4).

As it had been calculated that a load representing 50 percent of the machine test value of a box would cause failure in about 300 days, a long duration test was started with a solid fiberboard box made of W5s board. The machine test load attained for similar boxes was 558 pounds. Hence, a load of 279 pounds (50 percent) was placed on the box September 25, 1952. At the end of March 1953, 187 days had elapsed and it appeared that the box would sustain the load for the calculated 300 days.

These tests indicate that the curve shown in figure 4 may be used to determine the amount of dead load a box can be expected to sustain for specific periods of time. However, these tests were conducted with boxes that had not been previously rough handled and were not damaged. Rough handling prior to storage will reduce the compressive strength of the box and consequently will reduce the duration for a specific load.

Duration-of-load Data Applied to Boxes in Actual Storage Conditions: The duration-of-load information was recently applied to boxes in storage in military supply depots. A survey of three eastern supply depots showed that, without exception, when the actual load on the boxes in stacks exceeded the load the boxes could be expected to withstand (based on calculated compressive strength values and a specific dead load for a definite duration), failures had resulted. Conversely, when the dead loads were within the reasonable limits of the

Table 2—TEST VALUES FOR A BUILT-UP BOARD AND COMPONENT SHEETS

Material and description	Edgewise crush test of components: With Lb./in.	Edgewise crush test of components: Across Lb./in.	Edgewise crush test of built-up board: With Lb./in.	Edgewise crush test of built-up board: Across Lb./in.
Liners				
1. Fourdrinier kraft	15.9	9.8	----	----
2. Fourdrinier kraft	15.3	10.1	----	----
Fillers				
1. Plain chip	22.9	15.3	----	----
2. Plain chip	28.5	15.9	----	----
Total values	82.6	51.1	98.0	68.0

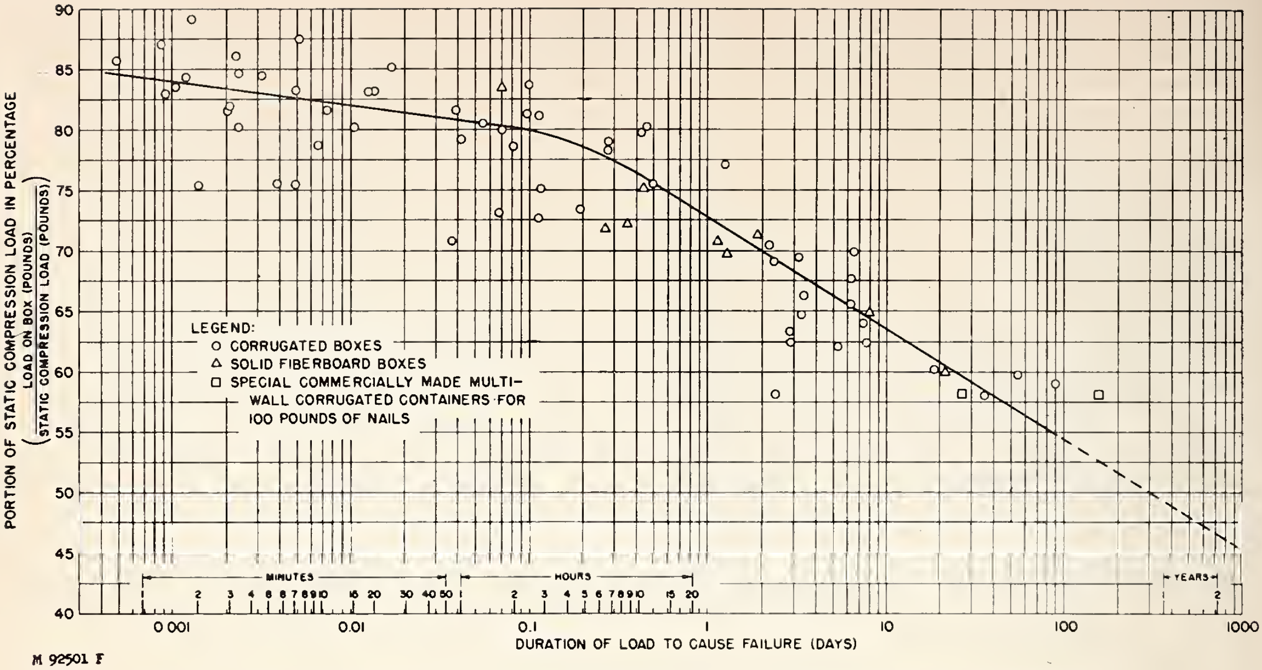

Figure 4.—The relationship of the compressive strength of a box (machine test load) and the dead load that will cause failure in specific durations.

data, the stacks were standing and no failures were apparent or imminent.

In the early part of the investigations, slight changes in the moisture content of the boxes during a test were found to reduce the duration, and it became apparent that the moisture content of a box could be related to its compressive strength.

Relation of Moisture Content of Fiberboard to Compressive Strength: From tests of the compressive strength of various boxes in several different atmospheres in conjunction with the duration-of-load study, it was found that the relationship between compressive strength of the box and moisture content of the fiberboard could be expressed by a formula (7). This formula provides a convenient means of finding the compressive strength of a box at any moisture content when its compressive strength is known for a specific moisture content. To make it easier to interpret the information, an alinement chart was constructed (fig. 5).

This chart was first used for corrugated boxes, but was found to apply to boxes made from solid fiberboard, as can be seen by comparing the actual test values with the calculated loads, determined with the chart, shown in table 5.

Table 3—SOME TYPICAL CALCULATED AND ACTUAL TEST LOADS FOR SOLID FIBERBOARD BOXES

Lot No.	Components	Basis weight Lb./1,000 sq. ft.	Size of box Length, Width, Depth Inches	Top-to-bottom compressive strength of box: Actual test Lb.	Calculated value Lb.
2S	Fourdrinier kraft liners; Chip fillers	279	16¾ x 12 x 5	830	795
6S	Fourdrinier kraft liners; Sized chip fillers	332	16¾ x 12 x 5	1,538	1,560
7SC	Fourdrinier kraft liners; Chip fillers	200	18½ x 7⅛ x 8⅞	448	431
10SB	Jute laminated liners; Chip fillers	375	16⁵⁄₁₆ x 12¼ x 9⅜	990	1,100
12S	Jute liners; Chip fillers	345	12¾ x 8⅜ x 8½	835	805

Table 4—RESULTS OF DURATION-OF-LOAD TESTS OF SOME SOLID FIBERBOARD BOXES AT VARIOUS DEAD LOADS

Static compressive strength of comparable box Pounds	Actual dead load on box Pounds	Ratio of dead load to static compressive strength Percent	Time to failure Days
484	340	70	1.35
475	340	72	.25
548	355	65	7.88
522	310	59	28.70

Uses for the Data: The data developed as a result of the basic study of fiberboard, both corrugated and solid, will serve several purposes.

First, it will provide a basis for charts and tables for use in preparing general specifications for various kinds of fiber boxes.

Secondly, having been applied in the Laboratory to commercially made boxes, the information will provide a means of checking quality control operations in commercial box manufacturing plants. To simplify calculations, the data have been incorporated into a box strength calculator (*10*) (fig. 6). With the calculator, the top-to-bottom compressive strength may be determined for any size box with various combinations of components fabricated into either corrugated or solid fiberboard. Also, the stacking loads for specific durations can be determined, as well as the compressive strength values for various moisture content values of the fiberboard.

These studies should also stimulate further basic research on fiberboard boxes and extend their use.

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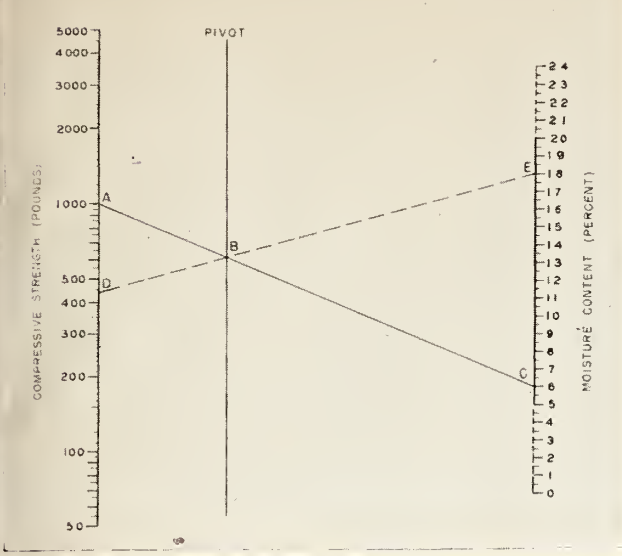

Figure 5.—The relationship of the moisture content of fiberboard and compressive strength of the box may be determined when the strength is known for one moisture content. Here it may be seen that a box having a compressive strength of 1,000 pounds at 6 percent has a compressive strength of less than 450 pounds when the moisture content is increased to 18 percent.

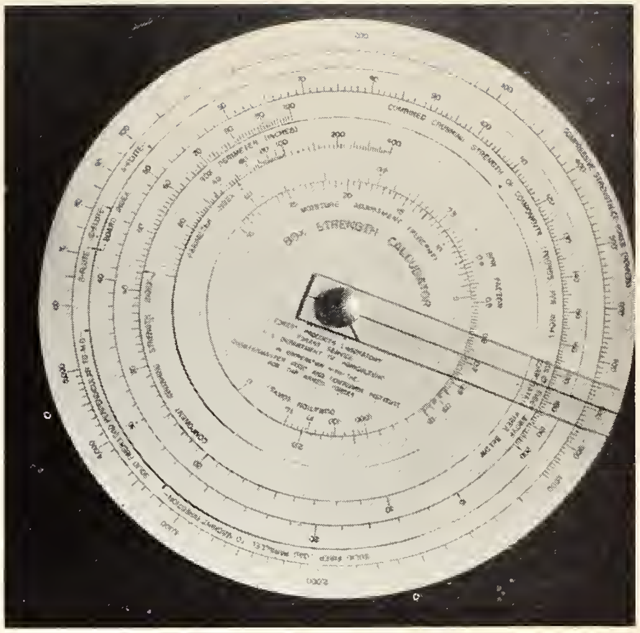

Figure 6.—This box strength calculator provides an easy means of determining top-to-bottom compressive strength of corrugated and solid fiberboard boxes. The influence of moisture content of the fiberboard and duration of load may also be determined by simple manipulations.

Table 5—ACTUAL COMPRESSIVE STRENGTH COMPARED TO CALCULATED COMPRESSIVE STRENGTH OF SOLID FIBERBOARD BOXES AT VARIOUS MOISTURE CONTENT VALUES. BASED ON ORIGINAL COMPRESSIVE STRENGTH OF 786 POUNDS AT A MOISTURE CONTENT OF 9.0 PERCENT

Box No.	Actual		Calculated compressive strength
	Moisture content Percent	Compressive strength Pounds	Pounds
1	6.32	865	940
2	12.49	651	615
3	18.29	389	410
4	25.83	261	242

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FACILITIES FOR PULP AND PAPER RESEARCH AT THE U. S. FOREST PRODUCTS LABORATORY

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Facilities for Pulp and Paper Research at the U. S. Forest Products Laboratory

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FACILITIES FOR PULP AND PAPER RESEARCH AT THE

U. S. FOREST PRODUCTS LABORATORY[1]

By

G. H. CHIDESTER, Chief
Pulp and Paper Division

Introduction

The over-all importance of the pulp and paper industry in the United States is not adequately measured by the money value of 6.8 billion dollars at which its annual output of products has been valued. Paper in the modern world is a key material of culture, commerce, and industry. Because of the great demand for paper in the United States, paper, pulp, and pulpwood have been imported for a number of years to supplement domestic production. At the same time, there is recognition of need within the country for the profitable use of neglected tree species (particularly hardwoods), thinnings from the forests, and the wastes of logging and lumber manufacture. It is appropriate, therefore, that a completely equipped pulp and paper laboratory is maintained as one of the eight major research divisions of the U. S. Forest Products Laboratory. The purpose of investigations in this pulp and paper laboratory is to increase possibilities of economical production, higher yield, and better pulp quality from native woods, including those of little or no present utility.

The wide usage of many and varied pulp and paper products has brought about constantly growing demands for such products. To meet these demands, it is necessary to supplement limited supplies of the relatively few coniferous woods that are the mainstay of the industry with other species that are available and to develop satisfactory conversion methods for these species. Utilization of other available species, many of which have little or no value at present, not only aids in supplying the increased demand for pulpwood but also enables improved forest management and provides higher returns from forest land.

Research in the pulp and paper division has the following objectives: (1) To improve yield and quality of pulps obtained in the sulfate, sulfite, soda, and other chemical processes, and in the semichemical and mechanical processes;

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[1] Maintained at Madison, Wis., by the Forest Service, U. S. Department of Agriculture, in cooperation with the University of Wisconsin.

(2) to develop and improve unit operations in chemical and mechanical processing of pulp, such as the bleaching operation; (3) to determine the relationship of fiber properties to the properties of pulps and papers; (4) to develop processing conditions for making paper, paperboard, wallboard, and other pulp and paper products; and (5) to find means for more complete utilization of species characteristic of various geographical regions.

To accomplish the objectives of this program, facilities are provided for conducting investigations and demonstrations through both laboratory and pilot-plant stages. The equipment consists of machinery for handling and preparing wood through the entire sequence of pulp and paper processing and several laboratories for testing pulps and papers. This equipment serves to meet a major objective in evaluating various species of wood for pulp and paper and is also adapted to investigations designed to improve and perfect techniques in pulp and paper manufacture.

Preparation of Wood for Pulping

The wood received at the Laboratory for experiments in pulp and paper making is often especially selected and cut so that the influence of any growth variables can be determined. Data are taken relative to growth conditions in the field, such as type of soil, climate, density and character of the stand, and other factors. At the Laboratory, determinations are made of various characteristics and properties, such as rate of growth; specific gravity; proportions of heartwood, sapwood, springwood, and summerwood; color; degree of decay; chemical composition; and other pertinent factors.

Pulpwood is peeled with hand tools or, if large quantities are being handled, on a bark-peeling machine. For chemical pulping, the peeled wood is chipped in a small, commercial-sized pulpwood chipper of standard design, and the chips screened to remove fines and over-sized pieces on a screen operating with a horizontal rotary motion (fig. 1). The chips can be conveyed mechanically to a chip bin or stored in metal containers until needed for cooking experiments.

Pulping Equipment

Chemical and Semichemical Pulping

Chemical- and semichemical-pulping experiments are conducted in vessels varying in capacity from beaker-size to a 225-cubic-foot digester. They are designed to operate under the widest possible range of conditions with a high degree of flexibility.

The smallest-scale experiments are made in calorimeter-type bombs, which are of stainless steel and have a capacity of 350 cubic centimeters. The bombs are heated in thermostatically controlled glycerine or oil baths. Experiments are conducted on this scale when the greatest accuracy is desired or when only a small amount of material is needed for subsequent analysis.

Small-scale digestions for producing 2 to 5 pounds of pulp, sufficient for making pulp-strength and bleaching tests, are made in autoclaves. For alkaline digestions, three cast-steel, spherical rotaries, which have individual volumes of 0.5 cubic foot and are jacketed for indirect heating, are available (fig. 2). Four stainless-steel, rotary autoclaves, which have volumes of 0.8 cubic foot and jackets for indirect heating, are used for acid, neutral, or alkaline digestions. The cooked chips are dumped from the autoclaves. Completely cooked chips are macerated with water in a tank equipped with a propeller-type stirrer. Semichemically softened chips are fiberized in an 8-inch, single-rotating-disk mill. The pulp is then screened on a diaphragm screen having a slotted screen plate that is 9 by 12 inches in size. The screened pulp is pressed in a hydraulic press, and the press cake is disintegrated in a specially designed apparatus for the yield determination.

Larger quantities of chemical and semichemical pulps are produced in two tumbling-type digesters having capacities of 13 cubic feet each (fig. 3). These digesters have steam jackets and can be heated indirectly or directly. They are constructed for pressures up to 400 pounds per square inch. One digester is made from steel plate and is used for alkaline digestions; the other has a stainless-steel lining and is suitable for either acid or alkaline pulping. When the digestion is completed, the chemical pulps are blown into a blowpit lined with stainless steel. The semichemically softened chips are discharged by dumping into a drain box and are then fiberized in a commercial-size disk mill, screened, and wet lapped. Approximately 50 pounds of chemical pulp or 75 pounds of semichemical pulp can be made in these digesters, which are sufficient amounts for short paper-making experiments on the Laboratory paper machine.

A much larger digester with a volume of 225 cubic feet (fig. 4) is used to supply pulp for extensive paper-making experiments or even for mill-scale, paper-making demonstrations. This digester holds the chips from 1 cord of wood so that approximately one-half ton of chemical pulp or three-fourths of a ton of semichemical pulp can be produced from each digestion. It is lined with stainless steel and is equipped for circulation of the cooking liquor through an external heater having stainless-steel tubes. The digester has a working pressure of 200 pounds per square inch. The chemical pulp is blown into a wooden blowpit and then is slushed from the blowpit through pipe lines to stock chests for subsequent screening and wet lapping. The semichemically softened chips are discharged through the bottom of the digester to a drag conveyor, which conveys the chips to a pipe line for flowing them to the chest supplying the disk mill.

Wood and metal tanks and other necessary auxiliary equipment are available for liquor preparation, pulp washing, and pulp and liquor storage.

Groundwood or Mechanical Pulping

The experimental pulpwood grinder (fig. 5) is a three-pocket, hand-fed type with a capacity of approximately 2 tons of air-dry pulp per 24 hours. The grinder is of commercial size with regard to the widths of the pockets (16 inches) and the diameter of the grindstone (54 inches). The face of the stone, however, is only 8 inches across. The wood blocks or log sections

used for grinding are cut 6 inches in length. The available grinding surface, based on length of wood and width of pockets, is 288 square inches, which is about one-fourth that of a commercial grinder using wood in 2-foot lengths. Both natural and artificial pulp-grinder stones of various types are available.

The grinding pressure is separately controlled in each pocket at any desired pressure up to 100 pounds per square inch of pocket area. The pressure is obtained by oil-operated pistons capable of delivering (1) a constant pressure with a rate of advance varying with the resistance offered by the wood or (2) a constant rate of advance with a variation in pressure within the operating range. The use of oil in the cylinders reduces both piston friction in the cylinder and piston-rod friction through the gland. To further reduce friction losses, the sides of the pockets are fitted with chromium-plated steel strips upon which the wood bears. These unusual methods of pressure control are highly desirable for experimental purposes because of their added flexibility. The piston stroke is approximately 24 inches. Therefore, each pocket, when filled to capacity with round bolts 6 inches in length, contains a gross volume of wood of about 1.25 cubic feet, or approximately 1 cubic foot of solid wood.

The grinder is powered by a two-speed, squirrel-cage induction motor capable of delivering 250 and 330 horsepower at the lower and higher speeds, respectively. The motor is connected to the grinder shaft through a three-speed gear reducer, thus making available six operating speeds of the grinder stone, ranging from 3,000 to 6,500 peripheral feet per minute.

Power-consumption measurements are corrected for motor efficiency and transmission losses so that the results are close to the actual energy required to reduce the wood to pulp. The grinder is equipped with temperature control for both the shower water and the grinder pit.

The groundwood pulp is screened on a rotary, scraper type of sliver screen, which has a screen plate 36 inches wide and 18 inches in radius. From this screen, the pulp passes through a flat-plate screen of standard design and over an experimental-sized wet machine.

In effect, this grinder is standard in all respects except stone width. In addition, it has features that permit the application of much exaggerated conditions of grinding. Thus the machine is adapted to basic research as well as standard applied studies.

For use in basic groundwood-pulping studies, there is also available a miniature size grinder for making only a pound or so of pulp in each experiment. The apparatus consists essentially of a small pulpstone (7-inch diameter and 1-1/2-inch face) directly connected to a 3-horsepower motor to provide a peripheral speed of the stone of about 3,200 feet per minute. The grinder housing and other parts are made of stainless steel to permit the use of corrosive chemicals in the grinder water. The wood is fed to the stone through a square tube extending about 6 feet vertically above the grinder. The area of wood in contact with the stone is 1 square inch. The pressure of the wood on the stone is adjusted by the use of directly applied weights. The machine is equipped with instruments for power measurement and temperature control. This type of grinder does not give results that are strictly comparable to those obtained

on a commercial grinder or the semicommercial type grinder described above, but is an adjunct to such equipment by providing a means of more precise observation of some of the operating variables.

Asplund Defibrator

The Asplund mill shown in figure 6 is a laboratory-size, stainless-steel defibrator for producing a coarse type of fiber, such as is used in the manufacture of roofing and deadening felts, insulating board, and hardboard. It consists of a cylinder of 2-3/4-gallon capacity, fitted with an axial shaft from which radiate four steel blades. These blades extend radially to within about one-eighth of an inch of the cylinder wall but only about one-hundredth of an inch from the four equally spaced, steel bed plates that extend the full length of the cylinder. The chip charge is approximately 1 pound on a moisture-free basis.

In operation, the chips in the cylinder are treated with steam at 175 pounds per square inch for 2 or 3 minutes. The defibrator blades are then rotated at about 1,700 revolutions per minute for 2 to 4 minutes. Next, the pressure is released by exhausting the steam through a cyclone. The front of the defibrator is removed, and the fiberized material is washed out.

Pulp Screening and Dewatering

Pulp Screen

Small, 9- by 12-inch, flat-plate screens are used for screening batches that consist of only a few pounds of pulp. A 12-plate flat screen is used for screening both mechanical and chemical pulps made in semicommercial quantities. Screen plates having slot openings from 0.006 to 0.016 inch wide are available, and the screen vat may be arranged to screen continuously in two stages to provide cleaner pulps. The drive mechanism provides for control of both frequency and amplitude cycles over a wide range.

Wet Machines

Two conventional-type wet machines are available (fig. 7) for converting screened pulp into a form suitable for handling and storage. The capacity of the smaller machine ranges from about 100 pounds of oven-dry pulp per hour for groundwood pulp to about 250 pounds per hour for sulfite or kraft pulp. The larger wet machine will handle approximately 50 percent more pulp per hour than the smaller machine. Both machines may be used to produce lapped or single-web pulp having a dry-fiber content of about 30 percent.

Pulp Bleaching and Purification

The pulp bleaching and purification facilities include equipment for pilot-plant work as well as for experiments on a laboratory-bench or 10-pound scale.

The pilot-plant equipment (fig. 8) is designed for batch operation and comprises a rubber-lined chlorinator equipped with shrouded impellers and a variable speed drive, a unit for either extraction or hypochlorite treatments, a stock-dilution tank, and a vacuum washer. From 60 to 200 pounds of pulp, depending on the kind and the consistence, can be processed in the chlorinator. Liquid chlorine is passed through an evaporator, and the chlorine gas is injected into the chlorinator through a pipe at the bottom impeller. The amount of chlorine used is determined by the weight of liquid chlorine taken from the cylinder.

After chlorination, the pulp drops into a stock-dilution tank and is then pumped to the vacuum washer on a platform above the reaction units. From the washer, the pulp falls through a chute to either of the two reaction units.

Circulation of stock in the unit used for extraction or hypochlorite treatments is obtained by means of a stationary draft tube enclosing a screw with a sweep arm at the bottom. All surfaces that come in contact with stock are stainless steel. Steam pressure up to 30 pounds per square inch can be admitted directly at the top. Circulation is satisfactory over a consistence range of 9 to 14 percent and from 35 to 150 pounds of pulp can be processed at one time. Stock is discharged by gravity to the dilution tank.

The drum of the vacuum washer is 3 feet in diameter, has a 12-inch face, and is equipped with a variable speed drive. A dandy roll is placed just ahead and a press roll just after the shower. A pin shredder is used to break up the sheet discharged by the washer. All parts of the washer that come in contact with stock are either rubber-covered or made of stainless steel.

A supply of water containing not more than 7 parts per million of total solids is available for bleaching and purification of pulp.

Disk Fiberizers

An 8-inch, single-rotating-disk attrition mill is available for fiberizing small batches of semichemical pulp or pulp produced in the Asplund Defibrator. It is shown in figure 9.

The fiberizer shown in figure 10 is a commercial-sized, double-revolving-disk attrition mill that can be used to fiberize larger quantities of materials, such as raw or partially cooked wood-pulp chips, screen rejects, straw, or waste paper. The two 36-inch-diameter disks or heads of the mill are fitted with interchangeable processing plates and have adjustable clearance between the plates. They are driven in opposite directions at a speed of 1,200 revolutions per minute by individual 125-horsepower motors mounted directly on the

mill shafts. Stock is fed to the mill by means of a screw-type feeding device equipped with a variable speed drive, and the flow of stock is further aided by showers of water that control the consistence.

Factors that affect the type and degree of processing obtainable with the mill are plate pattern, direction of rotation for the specific plate, clearance between plates, rate of feed, consistence, temperature, power load, and speed. Production capacity varies from 5 to 6 or more tons per day, depending on the material and the type of processing required.

Beaters

Three beaters with respective capacities of 5, 50 (fig. 11), and 125 pounds are available. The tub design of each beater assures rapid circulation and thorough mixing. The 50- and 125-pound beaters are driven by 15-horsepower motors through V-belts, the peripheral roll speeds of each being about 1,850 feet per minute.

The 50-pound beater has a counterbalanced roll, bronze tackle, and 5/16-inch-wide bars in the roll and 1/4-inch-wide bars in the bedplate. With careful handling, greaseproof stock can be prepared in this beater. The 125-pound beater has corrosion-resistant steel tackle, the bar width in both roll and bedplate being one-fourth inch.

Beating is generally done with the roll at the bedplate setting, the duration of beating being controlled by freeness and strength tests.

Jordans

Figure 12 shows the two experimental-size jordans and a metering device that controls the rate of the stock fed to them from the paper-machine chest. Stock feed lines are arranged so that the jordans may be used individually, in series, or in parallel. The plugs of the jordans are about 15 inches long with end diameters of about 8 and 11 inches. The bars are corrosion-resistant steel and are 1/8 inch wide at the face. Adjustable speed drives are used. Plug setting is achieved by pneumatic loading, which permits control from the central panel of the paper machine.

Fourdrinier Paper Machine

The paper machine at the Laboratory (fig. 13) is designed for small-scale production of a wide variety of papers, ranging from blotting to glassine and tissue to paperboard. It forms a sheet 13 inches in width. The machine consists of nine sections, the Fourdrinier forming unit; three wet presses, the last being a reversing type; a smoothing press; two dryer units totaling 20 dryers, with a size press between the twelfth and thirteenth dryers; and a calender stack and reel unit. All units of the machine are driven by a differential electric drive designed for precision control of speed and intersectional variations in speeds or "draws." The power units for each section

are energized from a synchronous alternator, which is driven by an adjustable-speed, direct-current motor of 10 horsepower. The speed range is from 11 to 325 feet per minute. Remote controls are provided for draw adjustment of each unit.

The stock is passed through a flat screen before going to the paper machine. The Fourdrinier has an adjustable, horizontal-orifice inlet for controlling the flow of the stock from a streamlined flow box to a 36-foot wire. It is equipped with 36 table rolls, 2-1/2 inches in diameter, and four flat suction boxes exhausted by a rotary, wet-vacuum pump. A dandy roll is mounted above the wire just after the second suction box. The shake arrangement is adjustable for frequency and amplitude. Trays are provided for returning white water to the system through a meter unit leading to the stock from the jordans. The top couch roll is removable for operations not requiring pick-up felts for lightweight papers.

The three press sections, which have 11-inch diameter, rubber-covered bottom rolls, and brass or granite top rolls, are of conventional design and are loaded pneumatically. The 15-inch diameter, semisteel dryers are steam heated. The calender stack consisting of seven rolls, is supplied with an auxiliary pneumatic system for controlling pressure to achieve various degrees of finish in the paper. The calendered paper can be wound on a reel or on 3-inch-diameter cores.

Equipment for Making Laminated-paper Plastics, Wallboard, and Hardboard

Machine for Impregnating Paper with Resin

Figure 14 shows the machine used in impregnating paper with resin for making laminated-paper plastics. The internal dimensions of the tower are approximately 9 by 14 inches, and its height is 11 feet. The heating chamber at the base measures approximately 20 by 20 by 13 inches. Vapors are drawn off from the top of the tower, together with the air that enters at the bottom of the heating chamber and passes through the tower.

The resin solution is applied to one or both sides of the paper by means of a roller mechanism. The treated paper passes into the top of the drying tower through a 1/4-inch-side slot and emerges at the bottom through a similar opening. The paper is pulled through the treater by a rubber-covered drive roll located at the bottom between the tower and rewind drum. The control of the drive roll permits a variation of paper speed from 3 to 10 feet per minute.

Assemblies of the resin-treated paper are molded in hot presses into laminated-paper plastic.

Formation of Insulating Board and Hardboard

For standard test purposes, a pulp mold, which is 18 inches square and has a suction lift, is used for making insulating-board and hardboard mats. The mats are dewatered and compressed to the desired thickness in a press. The insulating type of boards are dried in a forced-draft oven; hardboards are compressed to desired thickness and dried in a hot press.

The apparatus shown in figure 15 is used to determine the freeness of the pulp stock, and the 8-1/2-inch-diameter mat formed in making this determination can be subsequently compressed and dried as described above.

Presses and Dryer

For pressing insulating board, hardboard, and laminated plastics, several presses are available, most of which have automatic devices for control of the temperature and pressure. These presses, five in number, range in size of platen from 14 by 12 inches to 26 by 106 inches. The larger presses are used for fabricating fiberboard and wood-faced sandwich panels. A 72- by 32-inch Coe dryer, used primarily for drying plywood, is also available for drying fiberboard panels.

Corrugating Machine and Box-making Equipment

Corrugating board made on the Fourdrinier paper machine can be corrugated and single- or double-faced on a 52-inch corrugating machine. Facilities are available for fabricating and testing shipping containers made of corrugated-fiberboard.

Chemical and Physical Testing of Pulps, Papers, and Boards

Facilities are available for making complete chemical analyses of wood and pulp, including all the standard tests as well as special tests if desired.

The physical evaluation of pulp is made by processing it in a 1-1/2-pound-capacity test beater or a pebble mill. Samples are removed from the beater or pebble mill at regular intervals, the freeness is determined by means of a Schopper-Riegler or Canadian Standard freeness tester, and test sheets are made on a 9- by 7-inch sheet mold (fig. 16) or a British sheet machine.

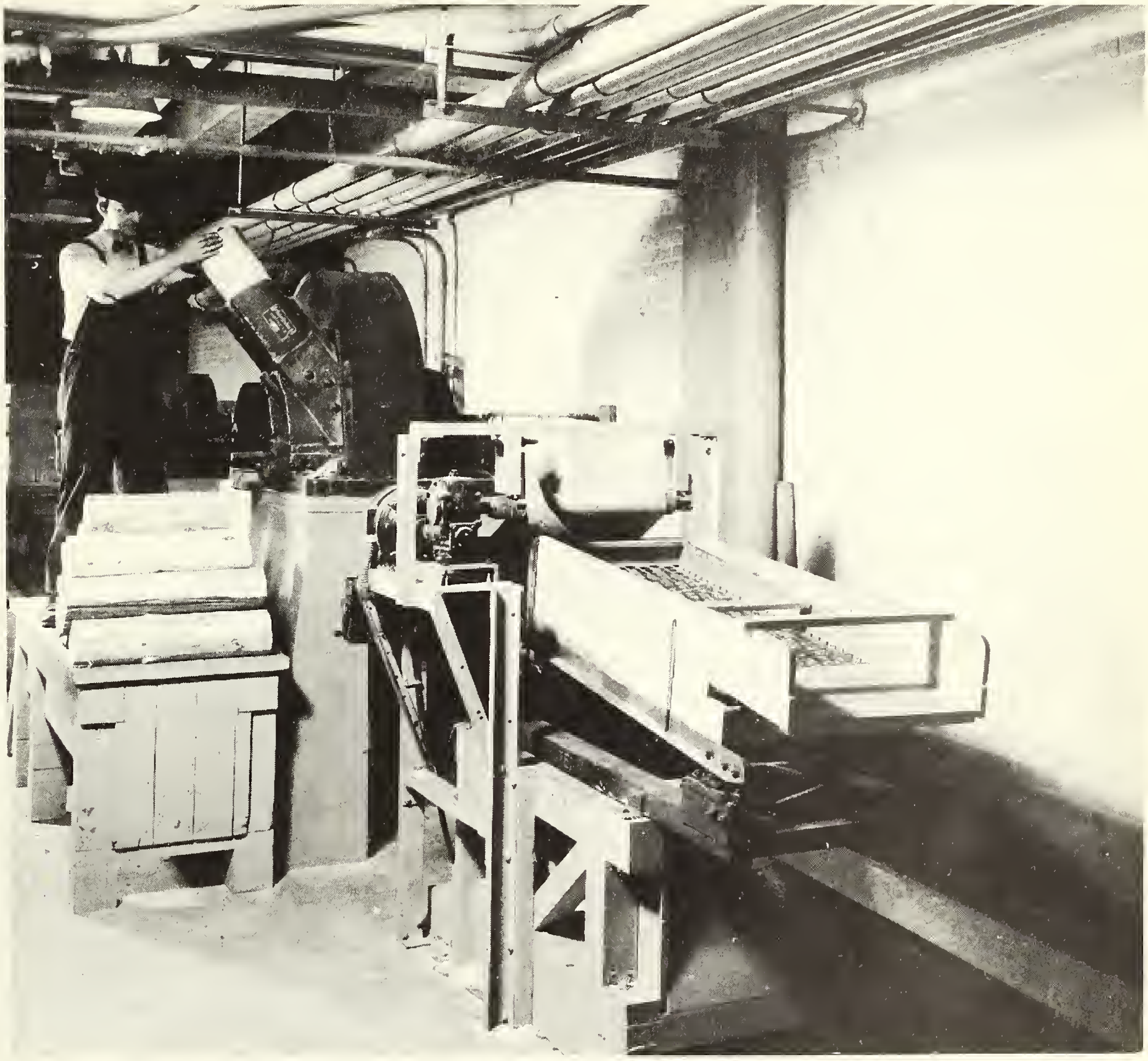
After the test sheets are dried in metal frames to prevent wrinkling, they are conditioned and tested in a room maintained at 75° F. and a relative humidity of 50 percent (fig. 17). Physical tests are made on these pulp sheets and on papers made on the Fourdrinier paper machine by means of Mullen bursting-strengt testers, Elmendorf tear testers, pendulum-type tensile testers, and folding-endurance testers.

Other equipment, which is used as required, consists of a densometer, glarimeter, opacimeter, reflectometer, moisture-vapor-transmission cabinet, abrasion

tester, smoothness tester, crush-resistance tester, apparatus for determining the fiber-size distribution of pulp by screen analysis, accelerated-aging equipment, facilities for the determination of the haze tendency of pulp on acetylation, a standard shredder and other equipment for the preparation and filtration of viscose solutions and the determination of their viscosity, and instruments for making visible ultraviolet and infrared absorption-spectra measurements. Standard machines are available for determining the strength, stiffness, toughness, dimensional stability, moisture absorption, and other properties of wallboard, hardboard, and laminated plastics.

Figure 1.--Pulpwood chipper and chip screen.

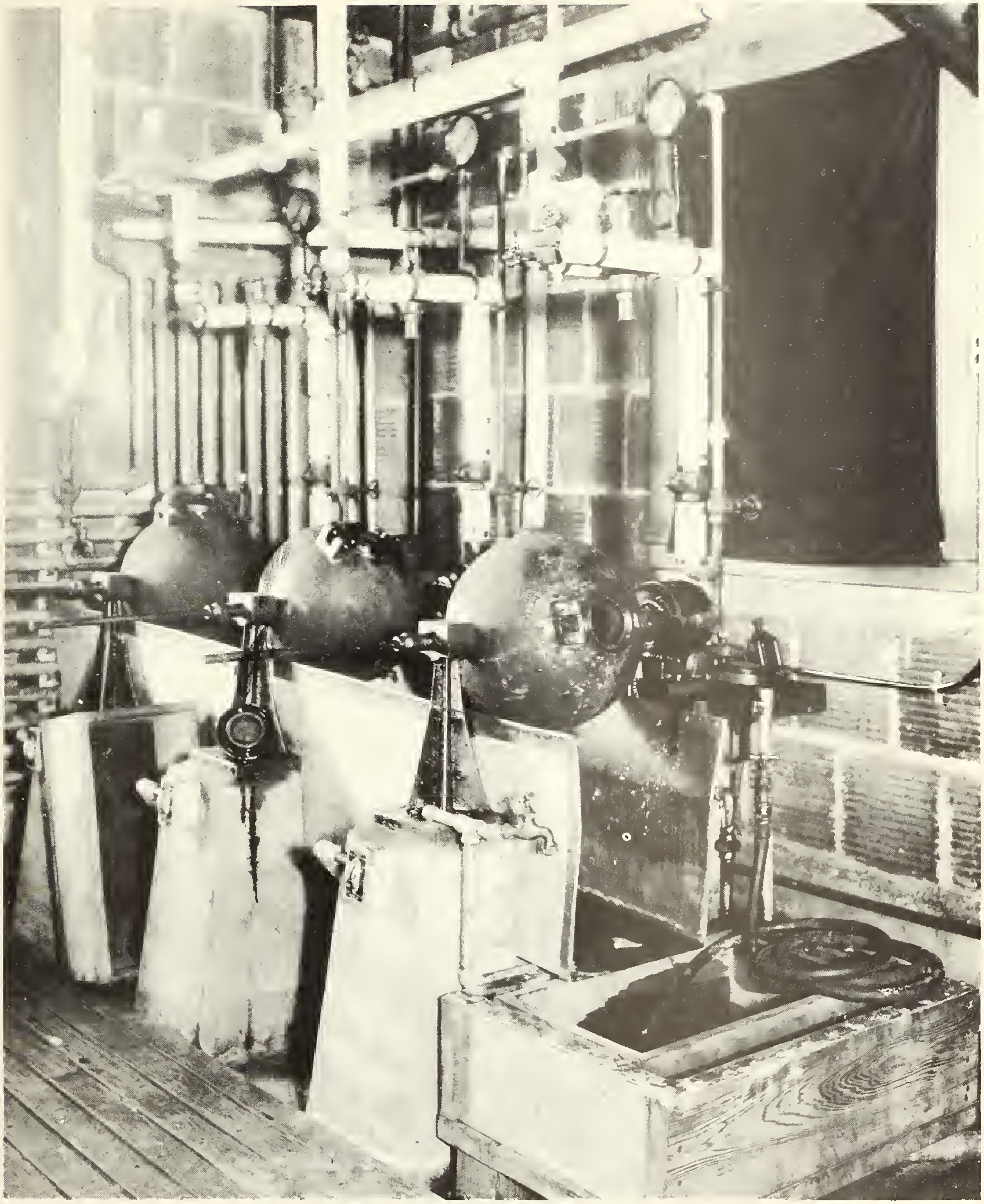
ZM 66512F



Z M 66512 F

Figure 2.--Spherical autoclaves used for 2-pound-scale alkaline pulping.

ZM 66513 F



Z M 66513 F

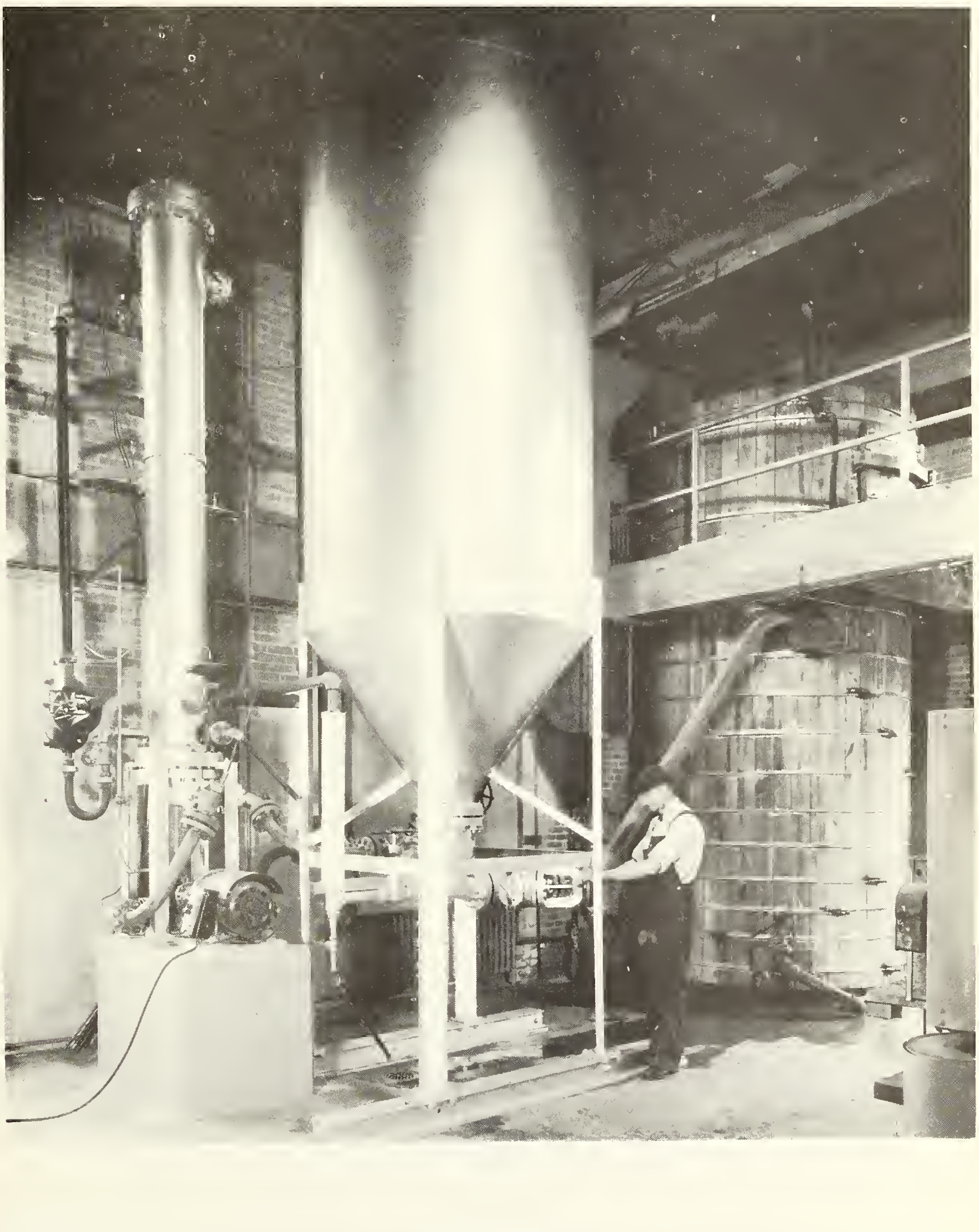
Figure 3.--Digesters used for 50-pound-scale acid and alkaline pulping.

ZM 66514 F

Z M 66514 F

Figure 4.--Digester used for 1,000-pound-scale acid and alkaline pulping.

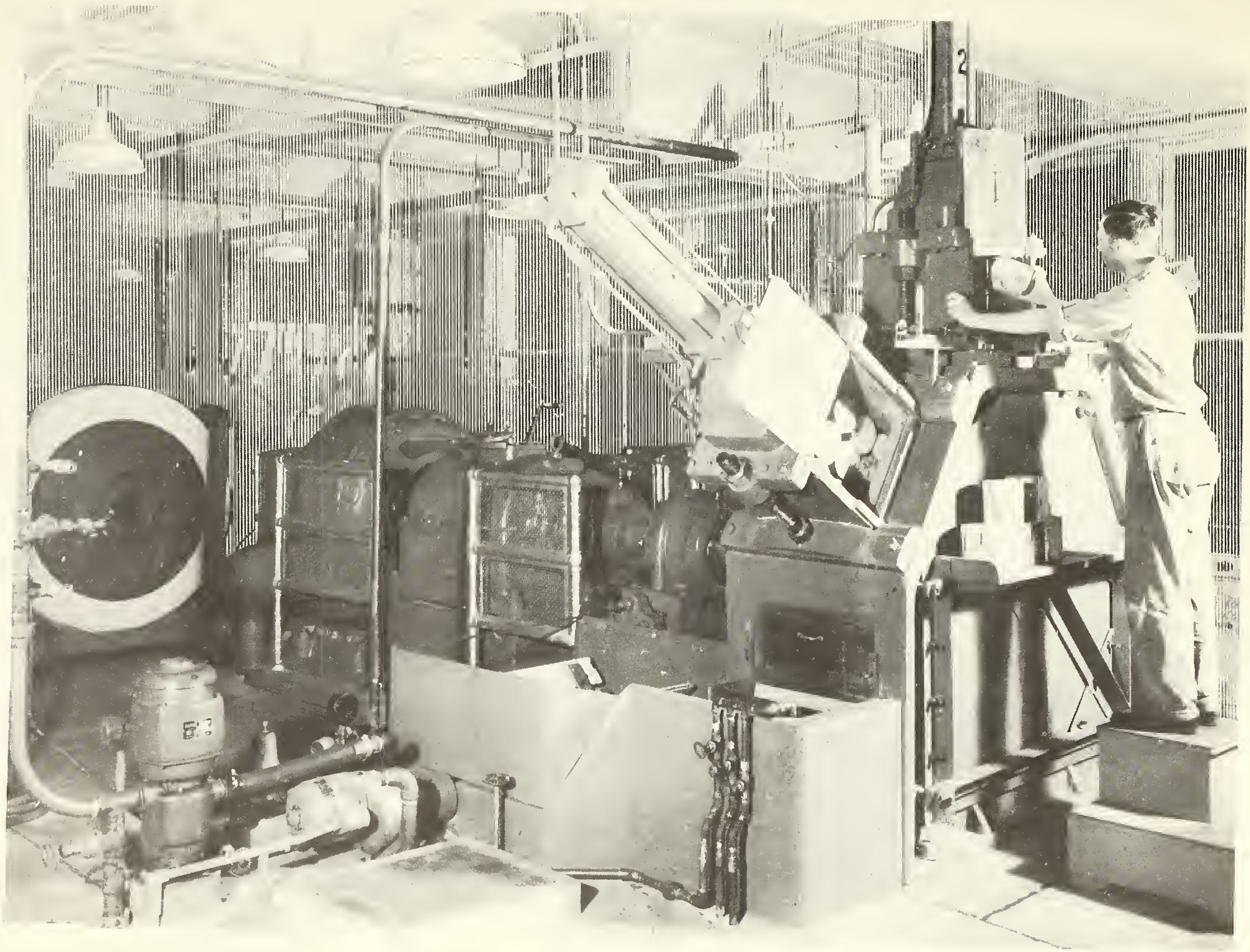
ZM 66515 F



Z M 66515 F

Figure 5.--Pulpwood grinder.

ZM 66516 F



Z M 66516 F

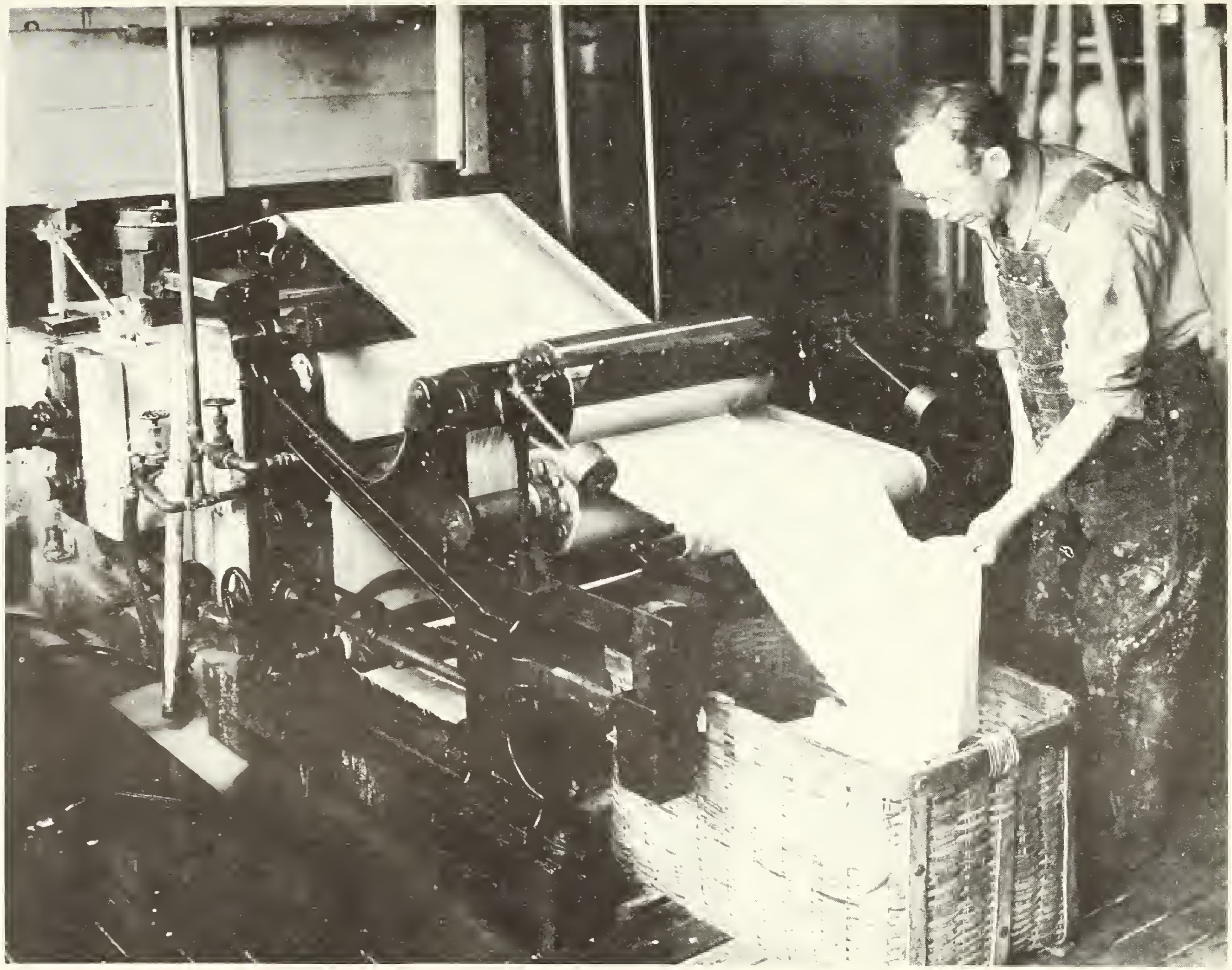
Figure 6.--The laboratory-scale, stainless steel Asplund Defibrator.

ZM 85763 F


2M85763

Figure 7.--Wet machine.

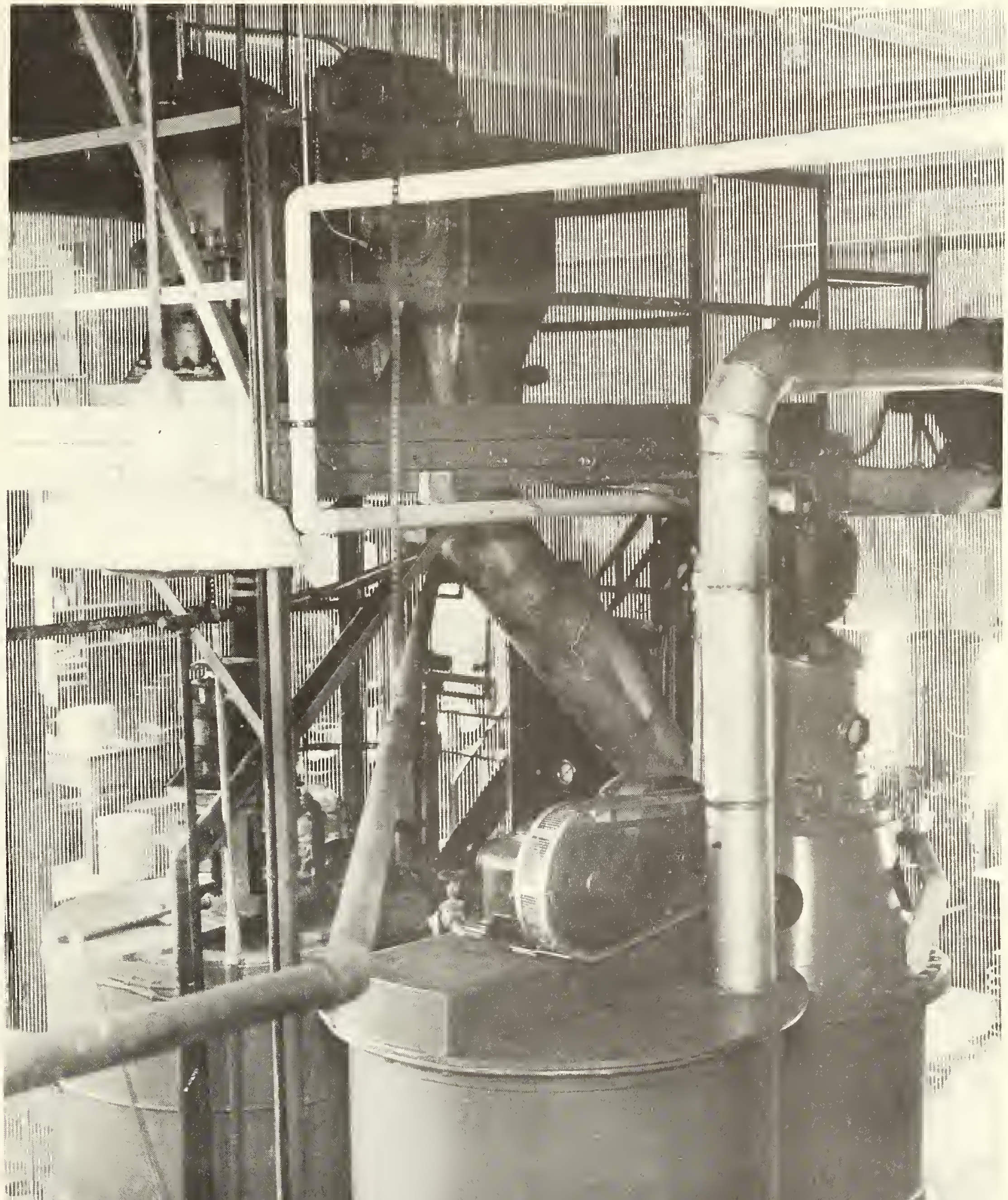
ZM 66517 F



Z M 66517 F

Figure 8.--Equipment for bleaching and purification of pulp.

ZM 66518 F



Z M 66518 F

Figure 9.--Eight-inch, single-rotating-disk attrition mill.

ZM 86129 F

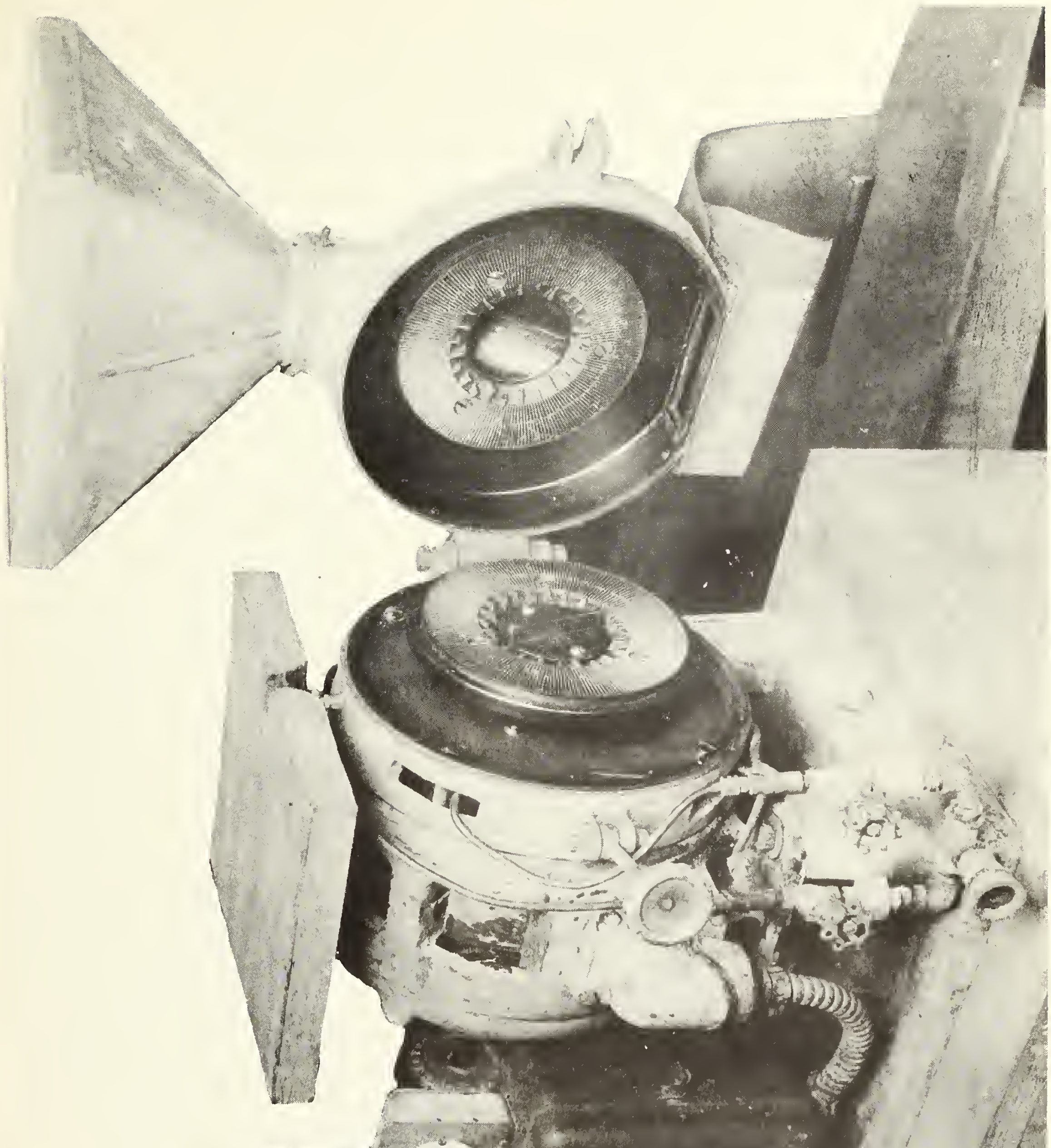

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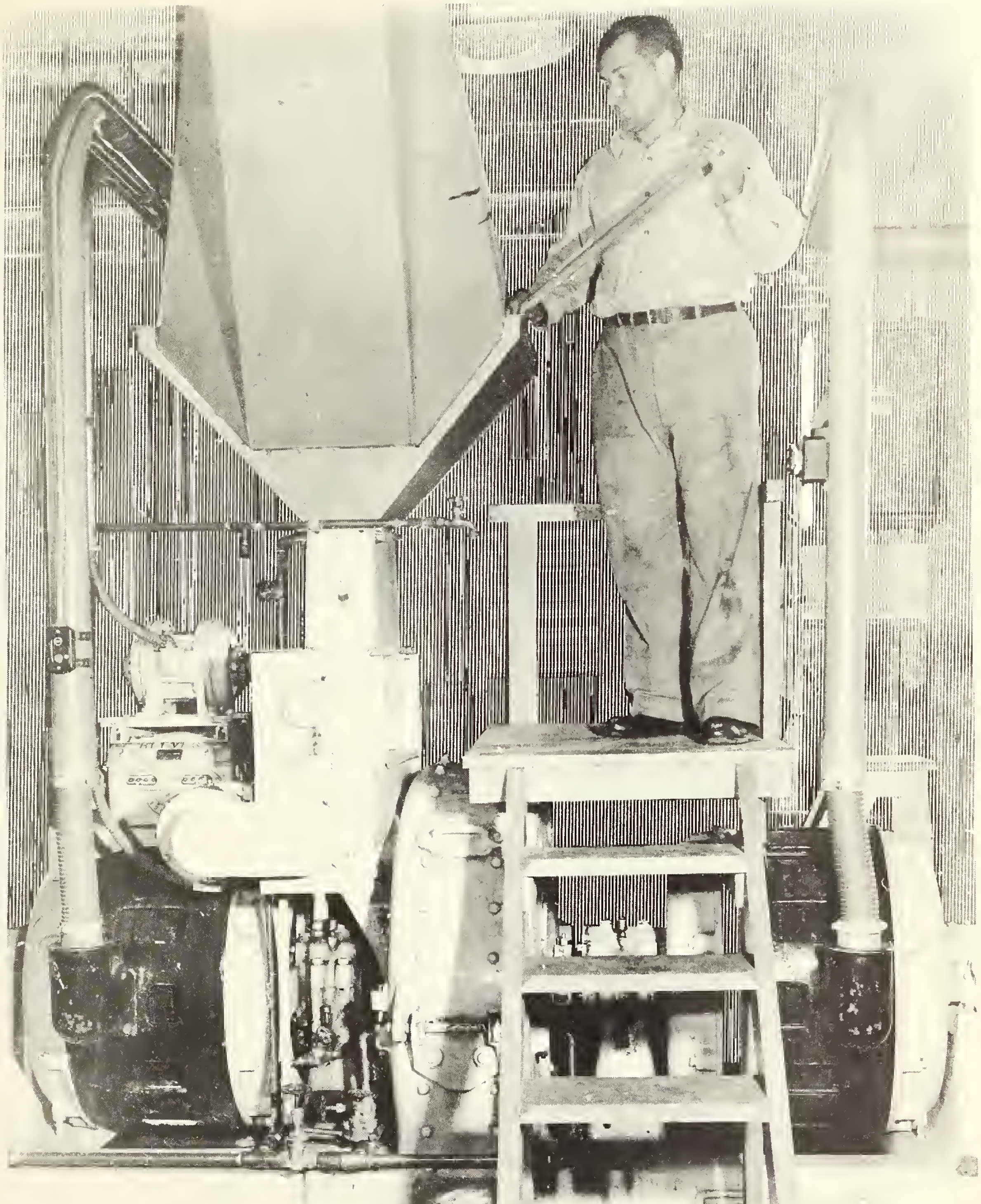
Figure 10.--Thirty-six-inch double-revolving-disk attrition mill.

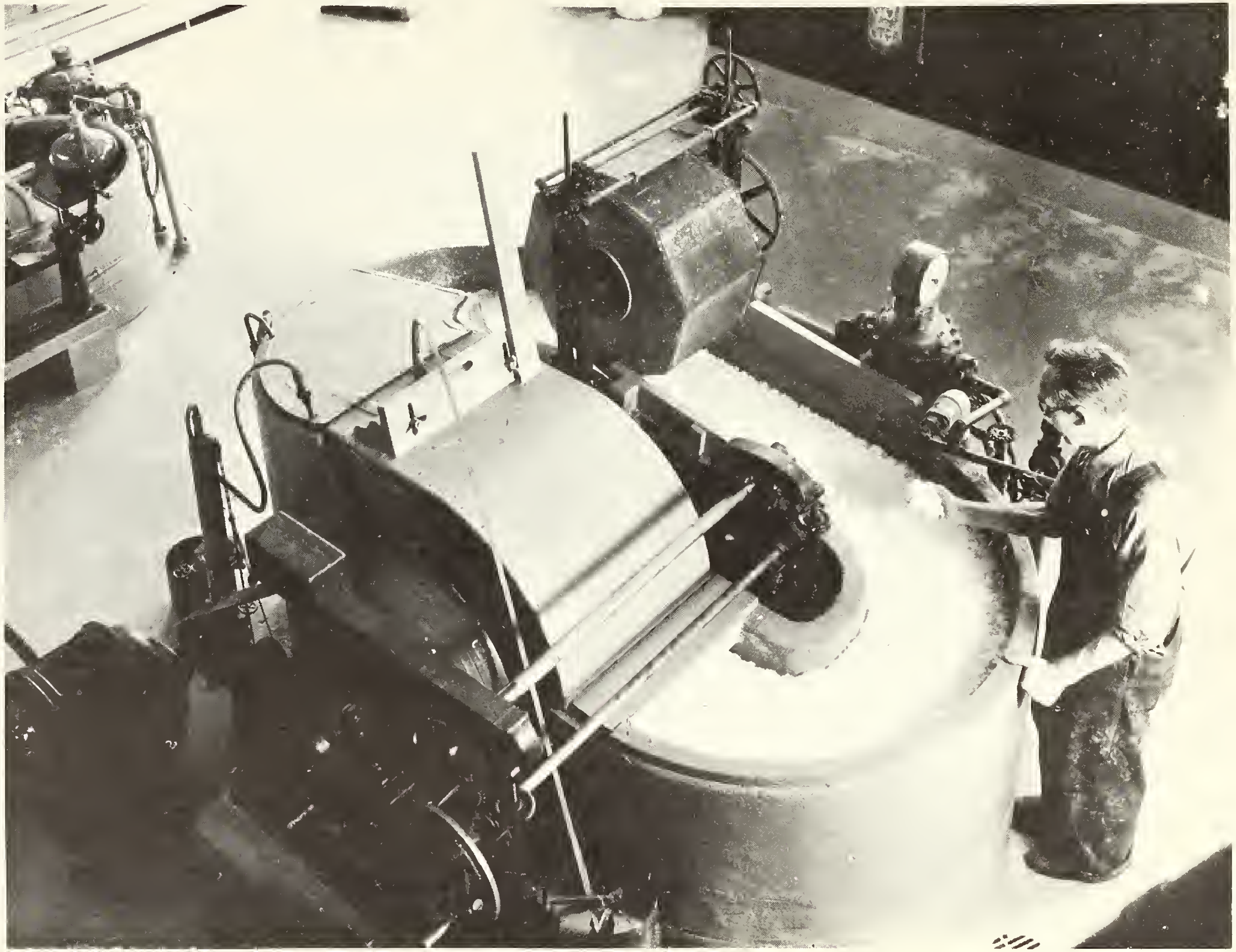
ZM 66519 F



Z M 66519 F

Figure 11.--Fifty-pound-scale beater.

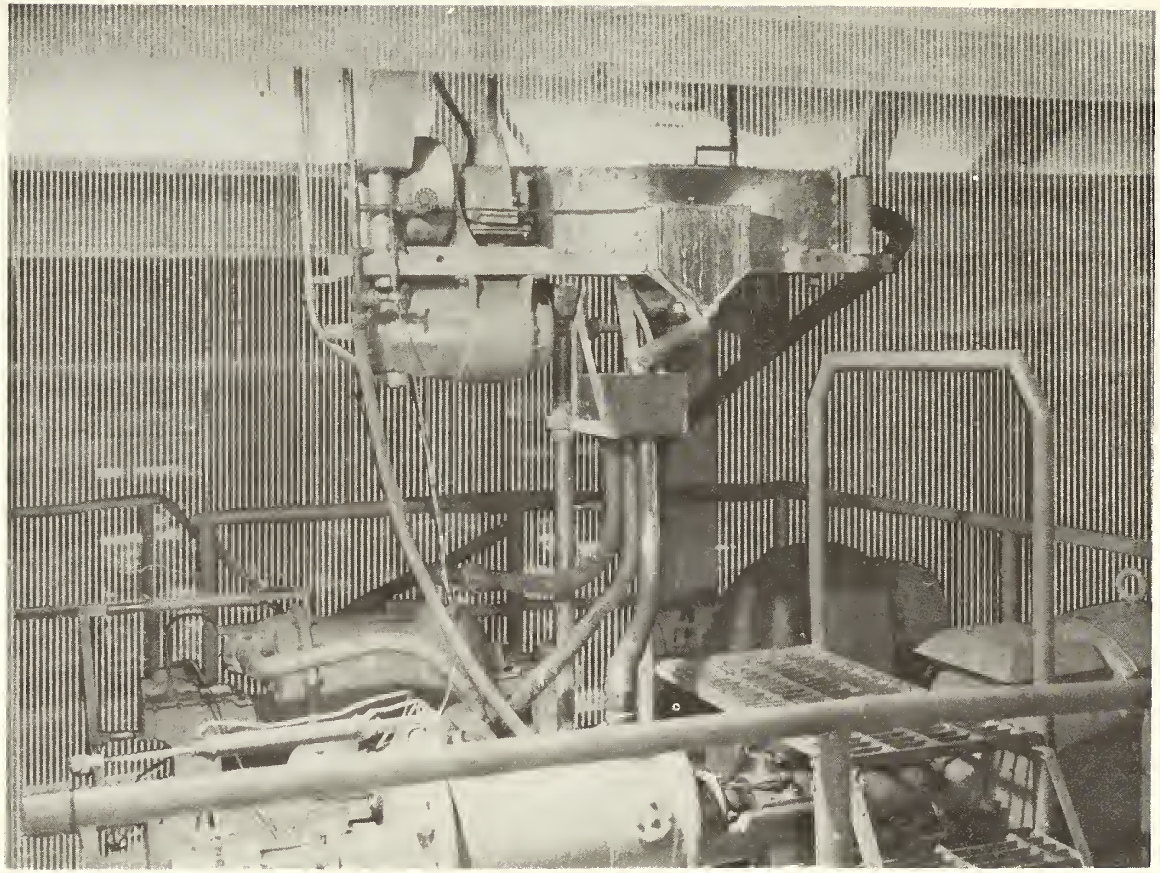
ZM 66520 F



Z M 66520 F

Figure 12.--Jordans and stock meter.

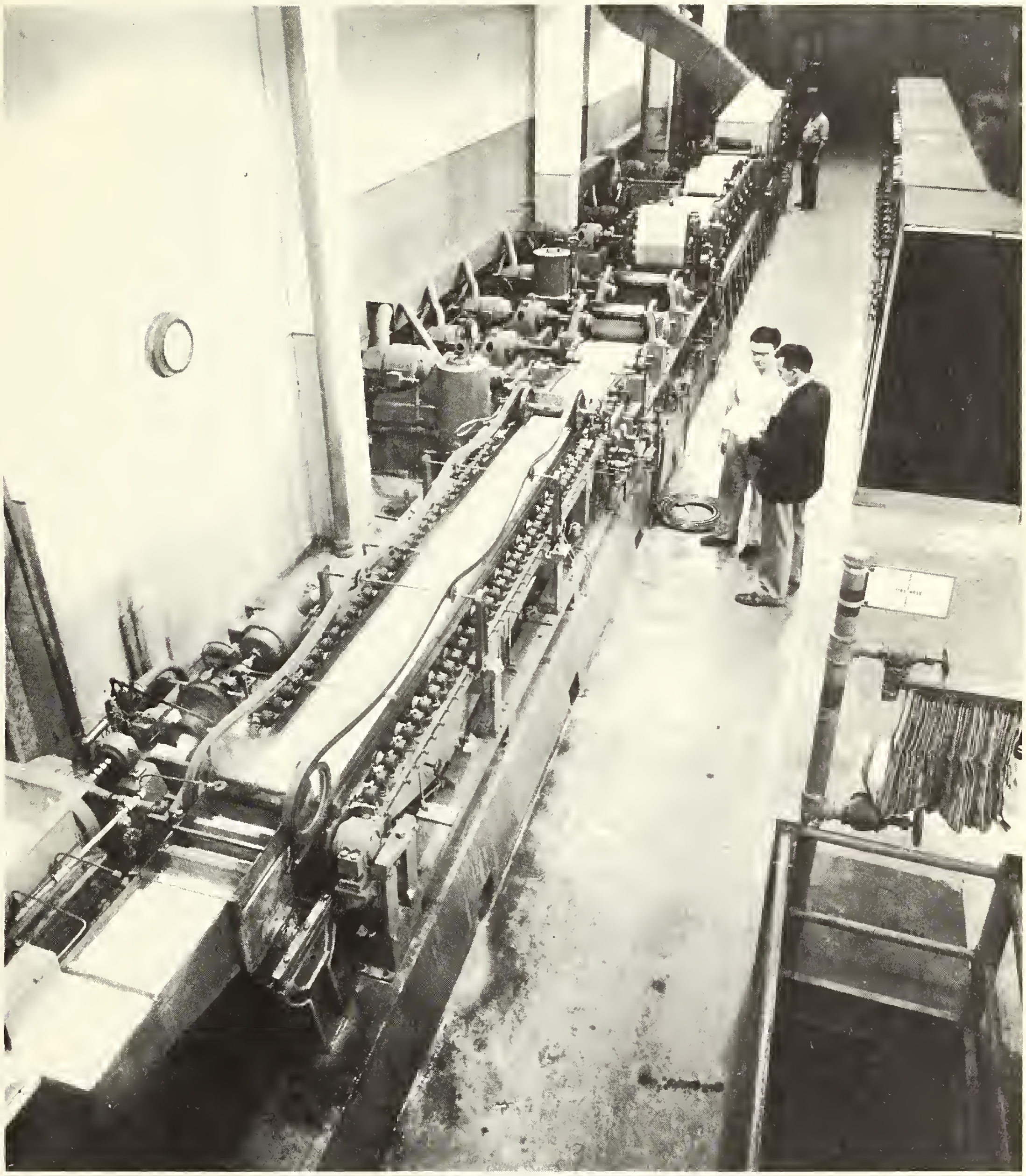
ZM 66521 F



Z M 65521 F

Figure 13.--Experimental Fourdrinier paper machine.

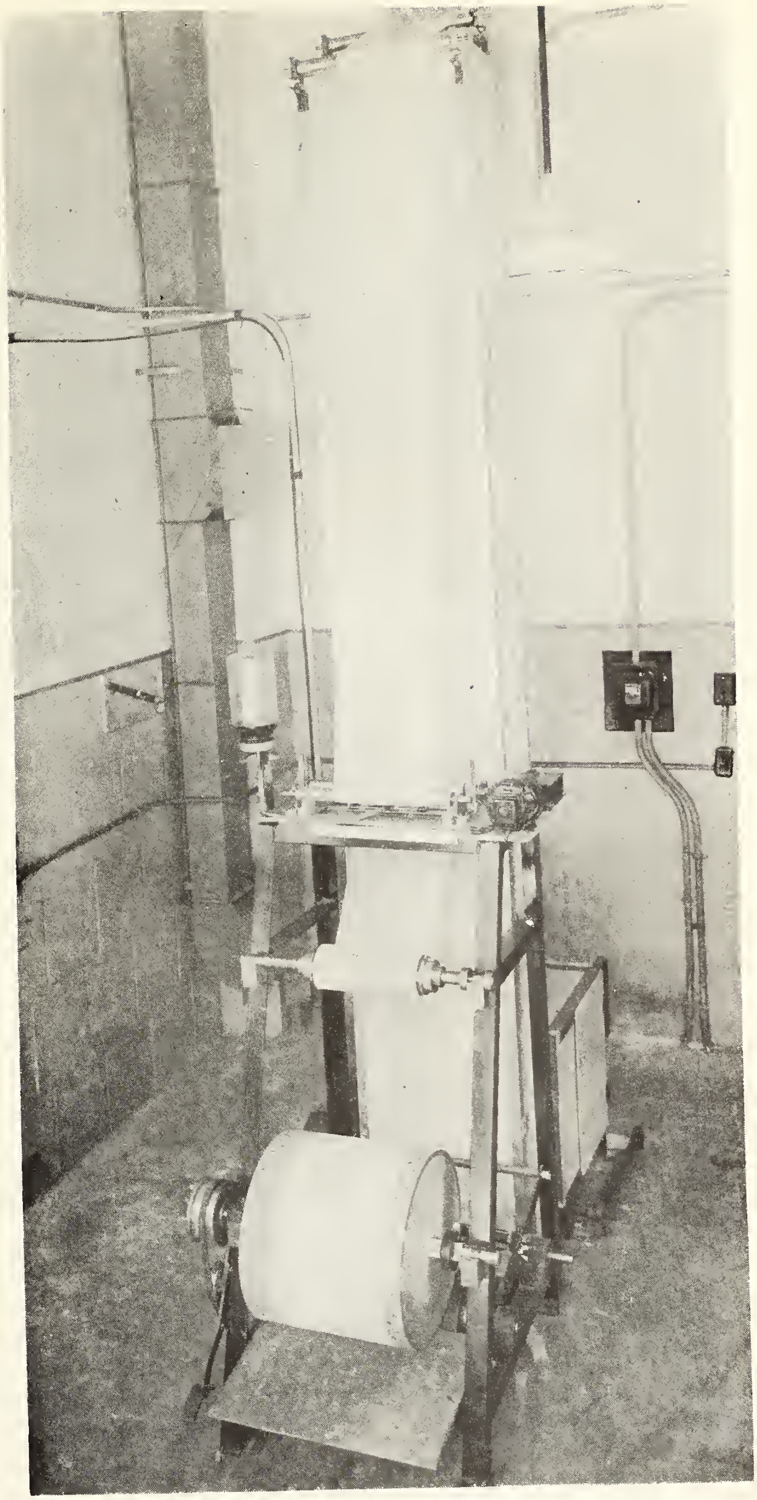
ZM 66522 F



Z M 66522 F

Figure 14.--Equipment for impregnating paper with resins.

ZM 66525 F



Z M 66525 F

Figure 15.--The Defibrator freeness tester and mat-forming machine.

ZM 85764 F

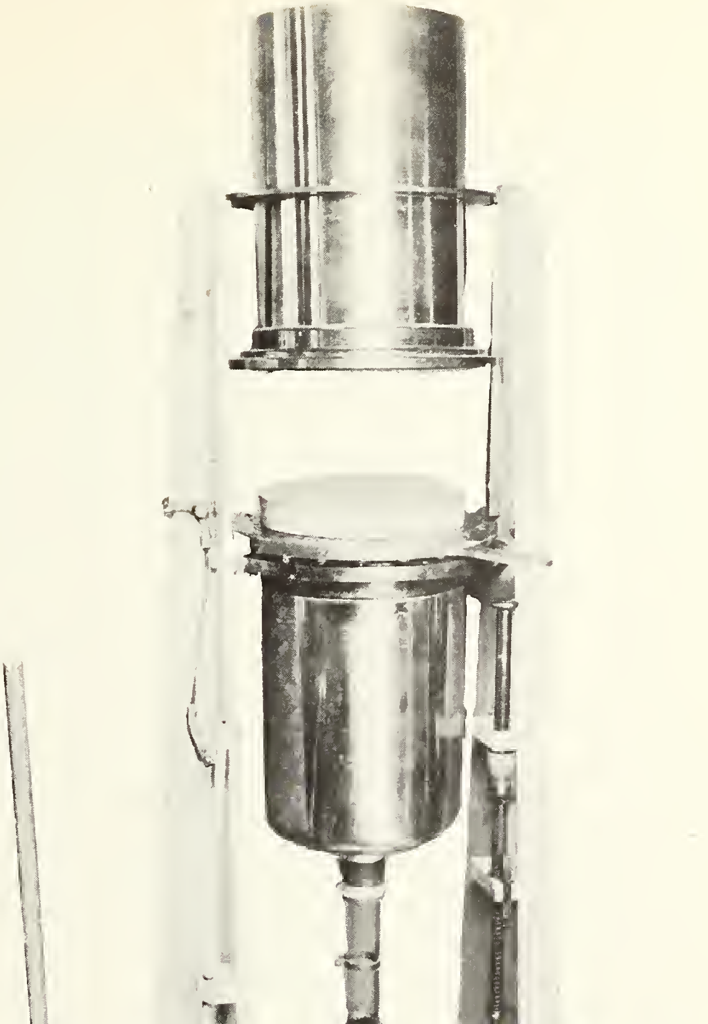
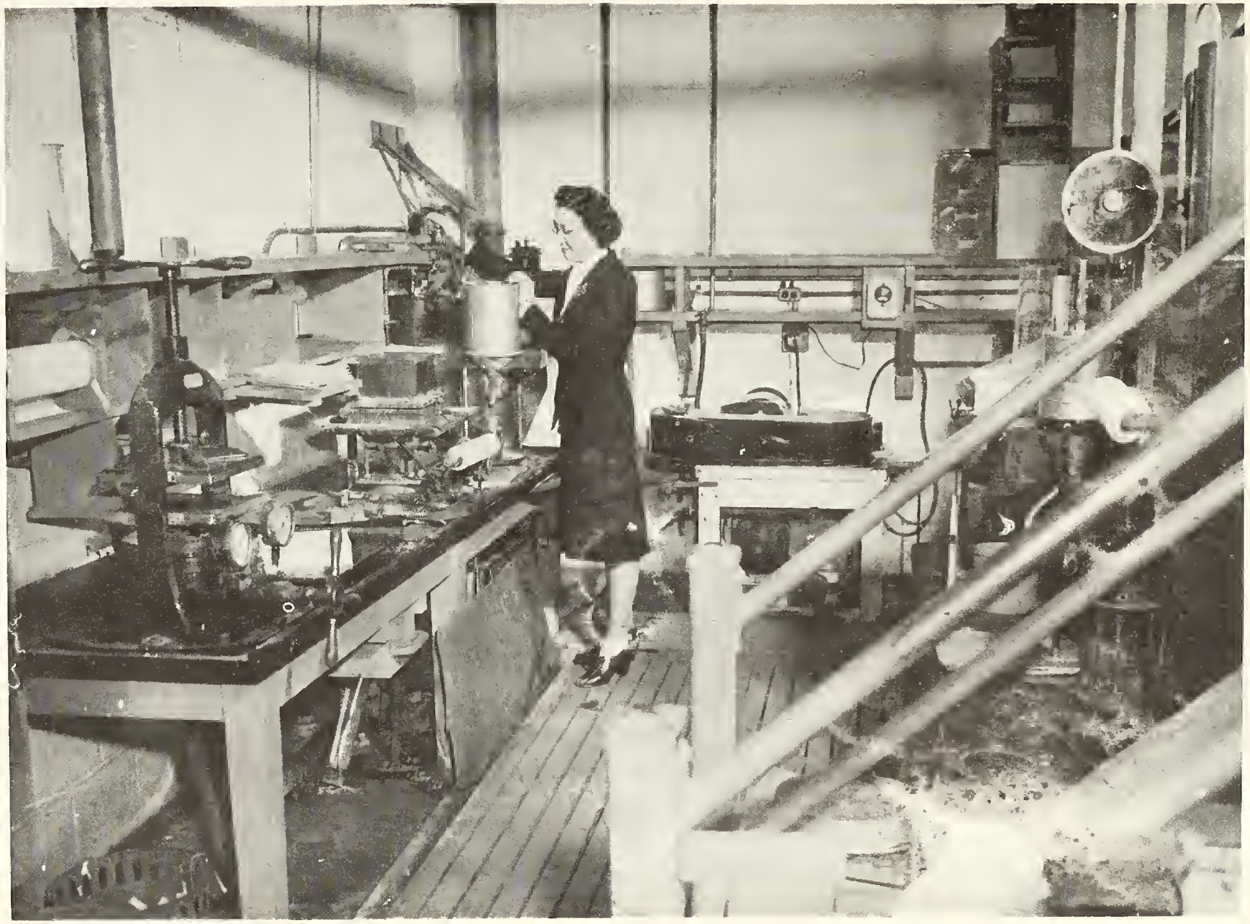

M 85764 F

Figure 16.--Laboratory for preparation of pulp test sheets.

ZM 66523 F



Z M 66523 F

Figure 17.--Humidity- and temperature-controlled room for testing pulp and paper.

ZM 66524 F

Samples of corrugating and corrugated boards made from English hardwoods

Machine Run 4380: 5-species mixture

Machine Run 4381: Hazel

4280